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ALTERNATIVES TO THE MANAGEMENT OF HAZARDOUS WASTES AT NATIONAL DISPOSAL SITES

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Finally, a warm sense of appreciation is extended to Dr. Robert Ottinger and his associates at TRW for their generous assistance throughout this program.

PART 1 SUMMARY

INTRODUCTION

Certain wastes, because of their chemical, physical, or biological nature, are hazardous to the environment and thus present special treatment and disposal problems. In 1970, the Environmental Protection Agency was directed by Congress to study the technical and economic feasibility of establishing a system of National Disposal Sites (NDS) for the centralized treatment or storage of these hazardous wastes. Some of the tasks of that study were: identify candidate hazardous materials; describe available methods for neutralization, recovery, or final disposal; determine capital and operating costs; evaluate legislative needs; specify candidate locations for such sites; and evaluate public attitudes toward them.

Because of the complexities of the problem and the potential impact the NDS System might have on specific local environments, EPA authorized Arthur D. Little, Inc., to evaluate alternatives to the initially proposed NDS System. National Disposal Sites were not defined by the legislative history, but it was commonly assumed that the NDS System would consist of 25 to 50 sites located in relatively isolated places, and would be required by law to receive any and all hazardous wastes from a fairly wide surrounding area, treat these wastes safely, and dispose of any residues in an environmentally safe manner.

During the study, it became evident that an NDS System might include any institutional or technical arrangement that would be administratively acceptable and that would fill the need for proper handling of hazardous wastes. The goal of the program discussed in this report was to define and evaluate on technical, economic, risk, and legal grounds the various alternatives for processing hazardous wastes.

OBJECTIVE, SCOPE, AND APPROACH

In the initial definition of tasks, four potential alternatives to an NDS System were outlined: (1) on-site disposal; (2) off-site disposal at a municipal facility; (3) on-site recycling; and (4) a transportable disposal system. During this investigation, however, it was found that these four could be incorporated into three, more general, categories: (1) on-site processing; (2) off-site processing; and (3) on-site pretreatment with off-site treatment and/or disposal.

The major emphasis of the program, therefore, was devoted to assessing differences among these alternative approaches in:

- the economics associated with waste treatment;
- the immediate risk to human safety, as well as the eventual hazard to the environment; and
- the legal and institutional issues that would have an impact on a national hazardous waste management system.

Most of the study effort was devoted to the wastes included in the toxic and flammable classifications for so-called Category I wastes.* By mutual agreement,** efforts on radioactive wastes, DOD items and explosives were limited, so most of our program was oriented primarily towards those Category I waste forms containing heavy metals, cyanides, pesticides, chloro organic solvents, and some other miscellaneous toxic chemical species.

To help in the economic analysis, the wastes were grouped according to the processes that should be applied for effective treatment. With this as a goal, all the wastes of interest – except for DOD items, explosives, and radioactive materials – were grouped so that four basic processes could be applied: precipitation of metals, followed by burial; oxidation to destroy cyanides; reduction to destroy oxidants; and incineration of organics.

The economic analyses were based on decision maps developed for this study, and for future programs requiring economic comparisons between alternative strategies. These graphical decision maps permited a comparison of on-site and off-site treatment in terms of the source (or sources) that generate the waste and can help frame the optimum approach

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* Category I wastes were established by TRW during their contract as candidates for treatment within a National Disposal Site System

** See first paragraph of page 13 for explanation of this decision.

for establishing a system of regional processing facilities. The data for these decision maps were derived from a series of field studies conducted to identify waste sources, including types and amounts of Category I wastes.

Federal and state laws and legislative frameworks were studied to learn whether any legal or institutional factors would militate against the conclusions made on economic grounds. Finally, each alternative was evaluated to determine whether any factors of risk would override the economic decision.

Although risk to people working with hazardous materials is, and should be, a major concern to society, those persons employed to handle, treat or transport the wastes were excluded on the assumption that they have freely chosen to accept the risk associated with their employment. Our study focused only on those risks to society from hazardous wastes which occur without its explicit consent.

Part 2 of this report describes the methods used to derive the data needed for the analyses of potential alternatives. Part 3 describes the results of the analyses. The thrust of the discussion is to describe the economic basis for suggesting a treatment site and then to show the impact of legal and risk factors on the economic decision.

CONCLUSIONS

Need for Off-Site Processing Facility

On economic grounds alone, off-site treatment facilities will be preferred by a majority of producers of industrial hazardous wastes, with the possible exception of those who handle explosives and dilute aqueous wastes. Although the shape and form of the processing system might vary, because of individual differences, this conclusion will be true for all regions of the United States. On the basis of this study, existing risk, legal, or institutional considerations will not alter this basic conclusion.

In addition to off-site processing (where the industrial source sends its waste, as generated, to an off-site processor), two other basic options are possible alternatives to be considered by a hazardous waste producer:

- On-Site Processing. The industrial source, either on its own or via a contractor, treats and disposes of its own waste. This option could include the use of a mobile treatment van (owned by an outside company).

- Combination of On-Site Pretreatment with Off-Site Treatment and/or Disposal. On-site pretreatment could be performed by the industrial concern that generates the waste or by a separate entity that operates a mobile treatment facility. The pretreated (concentrated) but still hazardous waste would then be shipped to an off-site processor.

Because of the economies of scale available to a central processing facility, these two options will not be as attractive to most waste producers as off-site processing without pretreatment. An exception to this occurs with aqueous waste streams containing low concentrations (ppm level) of heavy metal salts.

It is important to recognize that it is not necessary to decide whether all industrial hazardous wastes will receive off-site treatment but rather whether any will need off-site facilities. In fact, it is very likely that some industrial waste sources will choose to treat their own wastes, because:

(1) their particular volumes are sufficiently large to make on-site treatment more attractive;

(2) the nearest treatment center is too far away; or

(3) other factors – such as liability, fear of revealing trade secrets, image, corporate policy, etc. – override the decision made solely on economic grounds.

Nevertheless, the basic conclusion would still be that off-site (regional) facilities represent the most economically attractive option for a majority of hazardous waste producers.

Note that this conclusion holds even though the evaluation was purposely biased towards on-site processing. For example, it is recognized that satisfying environmental needs, especially during the ultimate disposal step, will be difficult for many on-site locations. However, this consideration was excluded in making the decision for off-site treatment centers in order to ensure a bias towards on-site treatment. *

Economics

The economics of on-site treatment and disposal of most hazardous wastes are high because of high fixed costs or high labor costs. Off-site processing benefits from the economies associated with a larger volume to be treated. In most cases, these economies outweigh the transportation costs required to get the waste to the central processing facility. Other factors, such as using one waste to treat another or using waste oil as fuel, were not factored into the cost of off-site processing to help ensure a bias for on-site treatment.

On-Site Treatment. On-site treatment might be attractive for two situations. Economics favor on-site disposal (burn or explode them) of industrial explosives that are either off-standard or overaged. Moreover, much off-standard or overaged material is considered too dangerous to transport; in fact, in several states it is against the law to transport them.

In addition to shipping untreated wastes, waste sources may find that some waste categories, such as dilute solutions that contain heavy metals, will be more economic to concentrate on-site to reduce the cost of transporting the original very large volumes to the off-site processor.

* An on-site bias was employed to help ensure that a conclusion favoring off-site processing would not be limited to the specific exarpples used in this study.

Mobile Waste Treatment. Mobile treatment facilities are not expected to become a major national treatment system, because the economies of scale derived from using a mobile waste treatment van for even "average" volumes of waste do not offset the added costs incurred for the extra storage facilities at the waste source.

Impact of Non-Hazardous Wastes. A central processing facility that only treats hazardous wastes will not be able to compete economically with one that also treats non-hazardous wastes. This conclusion rests largely on the economies of scale that are inherent when a facility treats all (therefore more volume) wastes. This problem area could have a serious impact on hazardous waste management and deserves further study.*

Economic Decision Maps. As an integral part of this program, a series of decision maps was utilized to aid in making decisions about whether a waste source would choose on-site versus off-site treatment. These maps were based on a general mathematical formula describing the economies associated with the total waste handling, treatment and disposal process. In addition to providing insight into the on-site versus off-site question, the maps were extremely valuable in studying the impact of having nonhazardous wastes included in a central treatment facility, and the overall area and/or waste volume that a central processor could handle when confronted with competition from other processors. It is recommended that this approach be expanded and further applied to the hazardous waste area.

Legal and Institutional Factors

Legal. The legal framework that applies to environmental problems generally, and to waste specifically, is in a period of rapid growth and development. The emphasis of these laws, with the notable exception of the Atomic Energy Act, has been on after-the-fact recovery of damages, rather than on prevention. Few laws relate specifically to "hazardous wastes." State statutes vary widely in this area. Federal laws apply through the establishment of effluent standards or regulation of transportation in interstate commerce. State laws are more directly applicable to the producer or processor of wastes via registration and permit systems.

Under existing laws, liability for a waste can be shared with an off-site handling or processing agent, but this liability is not likely to be removed entirely from the initial producer of the waste. If off-site processing is to be encouraged, it might be desirable for states to change their laws so that the responsibilities of the waste producer are minimal if the waste is handled by an approved off-site processor. This step should encourage waste sources to ship their wastes to "safe" locations and thus reduce the total number of ultimate disposal sites located throughout the country.

Institutional. In Congress and in state legislatures, various committees are concerned with environmental problems, but only a few have addressed "hazardous wastes" specifically – usually as a result of a spill or an incident of serious pollution. A similar pattern exists among executive agencies.

*See Appendix F, pages 207-215

In setting up a system for dealing with hazardous wastes, attention should be paid to existing systems that focus on similar problems. The atomic energy area is a prime example of an approach that deserves attention. However, a more universal approach to the regulation of radioactive wastes is needed than presently exists under the Atomic Energy Act of 1954. This new approach should provide for control of all radiation and radiotoxicity hazards, whether or not they are related to the national security mission of the AEC.

Regulations. There is a strong need for regulations which ensure that hazardous wastes are either properly treated, disposed of, or not created in the first place. Based on extensive field work, ADL believes that much of the material which belongs in a hazardous waste system is not receiving adequate attention – especially with regard to ultimate disposal.

Approach for Enforcement. EPA is concerned about hazardous materials primarily because they have a potential for causing undesirable effects. Therefore, the overall objective of a hazardous waste management system is to minimize the chances that these materials will create either short-term or long-term problems. Although there are a number of institutional approaches to attaining this objective, effluent and area monitoring is the only certain way of knowing whether hazardous materials reach the environment in an unsafe condition. In-put or inventory control, as well as process control (waste production or treatment), can be useful; but effluent monitoring will still be needed to ensure compliance.

Risk Factors

With only one exception, considerations of risk never changed a decision based on economic or legal factors.

Risk to the environment or to human health during transport is the principal difference between "on-site" and "off-site" treatment. Risk will occur during all steps involved in a hazardous waste treatment system – storage, transfer, transport, processing, and ultimate disposal. However, during processing, storage, or handling, operational steps are readily available to ensure that hazardous materials do not reach the outside environs of the plant site – or at least to drastically reduce such a possibility.

Except for explosives, the risk during transportation was found to be well below levels generally considered acceptable by the public. The explosives industry, as a standard practice, does not ship explosives that are off-quality. ADL agrees with this practice, believing that the apparent but undocumented risk, outweighs any economic grounds for shipping.

Need for Flexibility

Whatever approach is taken to establish a national system for managing hazardous wastes, it should be set up with flexibility in mind. For instance, materials will be added continually to the hazardous waste list as new effects are recognized and the selected system should be capable of dealing with them. In addition, within the system, procedures need to be applied so new wastes can be recognized and priorities assigned according to the degree of hazard or the need for immediate or special handling. Similarly, at the present time, there is very little good data on the composition, form, and quantities of hazardous materials being generated as industrial waste. This information needs to be obtained and, as it is, the data will likely help to reshape the overall waste processing system.

PART 2 METHODOLOGY

INTRODUCTION

As noted, the objective of this program was to compare – based on economic, legal, and risk criteria – alternative approaches for processing hazardous wastes. To attain this objective:

- Existing information was reviewed – from the literature, other EPA contractors, and private sources.

- The boundaries for the hazardous waste compounds, hazardous waste streams, treatment processes, and the alternative strategies were established and classified.

- Detailed data were developed for:

  - Waste sources (type volume, frequency and location),
  - Unit processes (technical feasibility and cost),
  - Transportation (types, costs, and distances),
  - Risks associated with handling, transportation processing, and disposal, and
  - Legislative factors that impinge on the problem.

- Means for evaluating data were developed.

- Evaluations and conclusions were prepared.

Part 2 describes the methodology that was employed to accomplish these tasks. The first section covers selection of wastes, processes and areas for field investigations. The next section discusses the classification of alternative approaches and criteria for selection between them. Next is discussed the manner in which the economic, technical, risk and legal data were generated and, lastly, a decision map approach for choosing between alternatives is described. Actual study results are presented in Part 3. More specific details for each subject area are provided in a separate volume containing the Appendices.

WASTES, PROCESSES, AND FIELD DATA

To compare the economics or risk associated with alternative treatment approaches for hazardous wastes, it was necessary to identify specific waste streams containing a known hazardous material. TRW (and later Battelle) developed a list of hazardous wastes, which it refers to as Category I Wastes, that contains almost 200 specific chemicals.* Since it was impossible, within the scope of this assignment, to develop information on the nature, form and volume of every one of these hazardous wastes, the TRW's list (Appendix A, Table A-1) was narrowed to a smaller, more manageable number.

Initially, the wastes were placed into 12 general categories according to their basic composition or properties. Recognizing the differences within these groupings, however, the 12 categories were divided into 34 sub-categories which described all of the chemicals on the TRW list as of September, 1972. These sub-classes are shown in Appendix A, Table A-2. Later TRW and Battelle added more chemicals to the Category I list (see Table A-3, Appendix A), but since these additions did not introduce new categories, and since this program was already under way, it was decided not to purposely change the original list (Table A-2, Appendix A). In this work, however, selected additional wastes (e.g., the chlorinated aromatics) were included where such inclusion was convenient as well as appropriate.

To aid the field work, as well as the process design for treatment facilities, it was next determined which basic chemical or physical processes should be applied to properly treat the wastes either at the site of the source of off-site at a waste treatment processing facility. At the same time, it was important to recognize that the chemicals listed in Table A-1 actually show up as components in mixed streams – liquid, solid or gaseous. Therefore, it also was necessary to consider treatment processes that are able to handle a given type of waste stream, rather than a specific chemical. With this in mind, the waste categories were regrouped according to the treatment processes that should be applied to similar waste streams. Eight process categories cover all of the wastes except those noted below. These eight waste streams are shown in Table 2.1 and a matrix showing which processes apply to the original waste categories is given in Table 2.2.

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*Reference is made in this report to material developed by TRW, Battelle, and Booz-Allen. These companies were also working on the processing of hazardous waste under contract to EPA as follows:

Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, Washington
EPA Contract No. 68-01-0762
Booz-Allen Applied Research Inc., Washington, D.C.
EPA Contract No. 68-03-0032
TRW Systems Group, Redondo Beach, California
EPA Contract No. 68-03-0089

TABLE 2.1

CHARACTER OF HAZARDOUS WASTE STREAMS

Code	Nature of Hazard	General Waste Stream Character
A	Concentrated heavy metals	Aqueous waste streams containing heavy metals like arsenic or mercury in concentrations above 0.1%
B	Dilute heavy metals	Aqueous waste streams containing heavy metals like chromium, cadmium, etc., in concentrations under 0.1%.
C	Dilute heavy metals with organics	Aqueous waste streams containing metals and organics in solution.
D	Heavy metal sludges	Wet cakes, slurries, and sludges containing precipitated heavy metals.
E	Concentrated cyanides	Waste streams containing more than 0.1% cyanide.
F	Dilute cyanides	Aqueous waste streams containing cyanide at concentration levels less than 0.1%.
G	Liquid wastes with chlorinated hydrocarbons	Liquid streams that can be incinerated directly without pretreatment other than filtering.
H	Organic wastes with solids	Organic-containing waste streams that require a rotary kiln incinerator.

TABLE 2.2

WASTE CATEGORIES*

Waste Type	Arsenic				Cadmium		Cyanides		Chromium		Mercury			Other Inorganics			Pesticides				Miscellaneous Organics			
	Antimony 1	Arsenates 2	Arsenites 3	Other 4	Soluble 5	Insoluble 6	Soluble 7	Insoluble 8	Chromates 9	Chromium III 10	Metal 11	Organo 12	Inorganic 13	Carbonyl 14	Inter halogen 15	Miscellaneous 16	Chloro organics 17	Halogen Gases 18	Phosphates 19	Nitro Cmpds. 20	Aliphatic with Halogen 21	Aromatic with Halogen 22	Organo Lead 23	Other 24
A. Concentrated Metals	+	+	+	+	+	+	–	–	+	+	–	–	+	–	–	–	–	–	–	–	–	–	–	–
B. Dilute Metals	+	+	+	+	+	+	–	–	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	–
C. Dilute Metals with Organics	+	+	+	+	+	+	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–
D. Metal Sludges	+	+	+	+	+	+	–	–	+	+	+	+	+	–	–	–	–	–	–	–	–	–	–	–
E. Concentrated Cyanides	+	–	–	–	+	+	+	+	–	+	–	–	+	–	–	–	–	–	–	–	–	–	–	–
F. Dilute Cyanides	+	–	–	–	+	+	+	+	–	+	–	–	+	–	–	–	–	–	–	–	–	–	–	–
G. Liquid Organics	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	+	+
H. Organics Requiring a Rotary Kiln	+	–	–	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	–	+	+	+	+

*Code

+ = Specific waste item may be present in stream
– = Specific waste item not likely to be found in general

To minimize duplication with the work of other contractors, only a minimal effort was placed on the inter-halogen compounds (sub-category 15), DOD compounds (sub-category 25), explosives (sub-categories 26-31) and radioactive elements (sub-category 32-34). In each case, it was felt that sufficient attention was being supplied by Battelle so that our limited program could best be focused on other wastes. Therefore, these ten sub-categories were not studied in the same manner as were the other wastes and thus are not included in the tables.

An understanding of the types, volumes, and frequency of industrial waste streams was developed via several routes. First, information developed by other contractors (Booz-Allen, TRW, Battelle) was used. Second, ADL professionals with expertise in a particular industry were utilized to generate a description of the wastes from that industry through the use of inhouse information, interviews, and plant visits. Finally, detailed information was obtained on specific waste streams from a processor of industrial wastes.

The specific data obtained from the regional processor provided a picture of waste streams that actually exist in the industrial world. Therefore, the field work by ADL was designed to ensure that the specific data was not biased in a way that would lead to erroneous conclusions concerning the need for off-site processing. (For more details, see Part 3 and Appendix B.)

DESCRIPTION OF ALTERNATIVES

In developing an overall strategy for collection and treatment of industrial hazardous wastes, one can classify the available alternatives on the basis of operational, technical and administrative options (Table 2.3). The operational options reflect overall concepts of possible ways to approach the problem -- on-site processing, mobile van, local processor, or regional processor. The technical options are what can actually be done with the wastes in a chemical or physical sense. Administrative options describe alternative ways in which a regulatory body can influence the shape of a hazardous waste disposal system. All three types (operational, technical, and administrative) are important and will greatly influence the final decision on how a particular hazardous waste should be processed.

This program focused primarily on the operational alternatives that might be available to an industrial plant generating a hazardous waste. Thus the interest was mainly in determining whether the waste source would, on economic grounds, choose to treat on-site, off-site, or via a combination of the two. The technical and administrative options are included in Table 2.3 for completeness only.

In deciding whether to select an alternative strategy or a National Disposal Site Concept for selected wastes, one must consider environmental impact, economic costs, health and safety factors, legal and regulatory restraints or incentives, and technical soundness. Criteria are necessary for the unit that generates the waste as well as for the company or agency that chooses to process the waste. Some of the factors that need to be considered are shown in Table 2.4. These can be divided into a few objective criteria (all economic), some very important but subjective criteria, boundary conditions that apply to all the criteria, and some miscellaneous factors.

TABLE 2.3

ALTERNATIVE APPROACHES FOR TREATMENT OF HAZARDOUS WASTES

A. Operational

1. On-Site Processing

   - Recycle – for internal or external use
   - Complete Treatment by Waste Generator – including disposal, if necessary
   - Final Treatment via Mobile Facility – using incineration or treatment and discharge of effluent at plant site

2. Off-Site Processing – either all in one place or combined among various off-site recycling treatment and/or disposal facilities

   - Private
   - Public

3. Pretreatment On-Site and Final Treatment Off-Site

   - Pretreatment by
     - Waste generator
     - Mobile van
   - Final treatment by
     - Processor (public/private)
     - Disposal (public/private)
     - Reclaimer

B. Technical Options

1. Recycle or Re-use
2. Destruction of a Chemical Form – i.e., oxidation, reduction, or incineration
3. Conversion to a Less Hazardous Form – via precipitation, complexation, etc.

TABLE 2.3 (Continued)

4. Dilution to Non-Hazardous Concentration Levels

5. Storage in Containers or Sites that are Designed for Long-Term Safety

6. Eliminate Source – change product or process so that hazardous waste no longer is formed

7. Some combination of the above

C. Administrative Options

1. Controls

- On Wastes – type or effluent concentration
- On Generator of Waste – process type or effluents
- On Processor of Wastes – processes and effluents

2. Incentives

- Tax Incentives or Relief
- Grants or subsidies
- Price Incentives

3. Organization

- Publicly-Owned and Operated
- Public Authority
- Privately-Owned and Certified
- Privately-Owned and Operated

TABLE 2.4

FACTORS TO BE CONSIDERED IN
TREATMENT OF HAZARDOUS WASTES

	Treatment by	
	Waste Generator	Off-Site Processor
OBJECTIVE CRITERIA		
Investment Cost	X	X
Operating Cost	X	X
Transportation Cost	X	X
SUBJECTIVE CRITERIA		
Risk – impact on environment	X	X
Public Relations – company image	X	–
Complexity – will operation fit in	X	–
Operational Feasibility – space, utilities, etc.	X	X
Nuisance Factor – willingness to cope	X	–
BOUNDARY CONDITIONS		
Legal Aspects – regulations and standards	X	X
Technical Factors – will technology meet current and future needs	X	X
Social Pressures – good neighbor, etc.	X	X
OTHER FACTORS		
Competition	–	X
Market Structure	–	X
Input Control	–	X
Storage Facilities	X	X
Waste Synergism	X	X

COMPILATION OF THE DATA BANK

Selection of Areas for Field Work

To ensure that the study would be based on realistic information, data was collected on hazardous waste streams in a number of different ways. Some data came from industrial firms processing wastes. Other information was obtained from industrial companies that generate hazardous wastes, while still other data was found in the literature. Throughout this data generation phase, however, it was felt necessary to focus attention in some depth on a particular geographical area rather than attempt to cover the total United States in a superficial manner.

In selecting a particular region for the field studies, attempts were made to ensure that the area:

- Contained sources of the wastes that had been selected for study;
- Had a variety of transportation forms available for carrying the wastes from one place to another;
- Did not have overly restrictive laws or regulations which seriously limit the choice of alternative strategies;
- Had several types of geography and population centers.

The New Jersey-Eastern Pennsylvania region was selected for most of the field studies because:

- Specific data on the nature of selected individual industrial waste streams – waste form, volume, and concentration – are available.

- New Jersey and Pennsylvania have been active in developing programs oriented towards dealing with hazardous waste problems.

- Major segments of the chemical manufacturing industry, as well as users of those chemicals considered as candidates for an NDS system, are located in this region.

Assumptions and Cost Factors Used in the Process Economics

The economic comparisons of treating various waste streams on-site, versus some alternative off-site treatment, were based on actual conceptual design and sizing of on-site facilities for specific waste streams as indicated by the field survey (both as to volume of waste produced per day, week or month, and concentration of this waste). This same process was then assumed to be used in an alternative off-site facility. In each case, the alternative selected was the least expensive on-site processing steps that would still meet the estimates of future environmental standards or guidelines. If a cheaper off-site process exists the methodology is still correct in that it biases the results in favor of on-site processing.

The on-site facility was conservatively assumed to buy all of its fuel and neutralization chemicals for the specific waste being treated; that is, there would be no synergism of mixing acid and basic wastes or any fuel value contained in any of the waste. This same constraint (no synergisms, all fuel and neutralization chemicals purchased) was assumed for the off-site facilities; to the extent that the off-site facilities could mix acid and basic wastes and use waste oil for fuel, the methodology again prejudices any comparisons in favor of on-site treatment.

To repeat, sizing and costing were done for the on-site system. The various processes are described in Part 3 and detailed in Appendix C. For the alternative off-site waste treatment facilities, capital investment was estimated to vary by the 0.6 power of the throughput. For example, a plant 4 times larger would cost only 2.3 times more than the base plant, $4^{0.6}$.

This short-cut method is well documented for the types of processes used in waste treatment and is sufficiently accurate for the intended uses.* It was also assumed that labor varied as the 0.6 power of the throughput but an allowance was made for incremental labor (part-time assignment to waste processing) at the on-site facility of a production plant.

To the extent that an off-site facility will have more waste to handle and therefore would operate two or three shifts per day instead of one (assumed in some cases for the on-site facility and also assumed for the off-site facility) such savings at the off-site facility would again prejudice the method in favor of on-site processing.

*Rase and Barrow, Project Engineering of Process Plants, p.51 John Wiley & Sons (1957).

One exception to the 0.6 rule that may crop up and favor on-site processing would be the invention of small preassembled packaged plants for a specific waste treatment process. Such prepackaged plants – built by the hundreds, with economies of mass production – would be cheaper than indicated by the 0.6 factor rule. These types of small plants may well be designed, for example, to remove heavy metals or cyanides from plating baths (because of the thousands of plating operations in the country), or to remove chromates and zinc from cooling water, again because of the large number of cooling water installations on commercial and industrial buildings However, even though this would lead to a reduced volume of the original waste form for treatment at a regional processor, there still would be a need for ultimate disposal facilities for the concentrated wastes.

As the scale of process increases, especially in automatic processes, the labor does not go up in accordance with the 0.6 factor except for sampling and analysis. However, again, the assumption of the 0.6 rule puts the bias in favor of on-site processing.

Land cost was not entered as a factor in the cost of either on-site or off-site processing, since, in many cases, land would be more expensive, and harder to come by at the on-site installation. Once again, if a bias exists it would be in favor of on-site processing.

The overhead rate for on-site processing was taken to be the same as for off-site (50% of direct labor). Other cost factors were selected on the bases of typical factors for the United States as follows:*

Electricity	1¢/kilowatt hour
Water	5¢/1,000 gallons (1.3¢/1000 liters)
Fuel	10¢/gallon (2.6¢/liter)
Neutralization chemicals	Costed consistent with use rate but again, no economies of scale attributed to off-site processing
Depreciation	5 years
Maintenance	5% of capital investment
Insurance & local taxes	2% of capital investment
Labor rate	$5.50/hour, including fringe benefits

*Many literature sources provide data and discussion of these factors. An example is "Fundamentals of Cost Engineering in the Chemical Industry" by H. C. Bauman (Reinhold 1969). In using these sources, appropriate revisions were made to account for 1973 values.

The cost of money was not included in the calculations for either the on-site or the off-site waste treatment processing. Neither was there an allowance for profit in the case of the off-site processing. Rather, the approach was to calculate the "cost to society" by either method.

For off-site processing, transportation costs were taken to be 0.03¢ per gallon (0.008¢/liter) per mile transported.

Risk Analysis

Introduction. Under normal operating conditions, the handling, storage and processing of hazardous chemical wastes for the purpose of disposing of them should not present any undue risks to society. Indeed, the disposal of chemical wastes is an operation which inherently reduces risks to society. Only when abnormal events (accidents) occur during the disposal operations may society become exposed to the hazards associated with the particular waste that may be released as a result of the accident. Society may then become exposed to such hazards as the thermal effects of a fire, the air blast of an explosion, the release of a toxic gas into the atmosphere, the release of a polluting liquid into the drinking water supply, or the release of harmful radioactivity.

Because these risks could affect the results of our economic comparisons of alternatives, the risk level represented by the various categories of wastes included in the study was calculated by:

(1) Arriving at methods for quantifying the various types of risks to which society may be exposed from accidental releases during disposal of hazardous chemical wastes.

(2) Utilizing these methods to compare the risks of alternative locations for off-site disposal.

(3) Calculating absolute levels of risk for disposal operations and determining whether these risks are acceptable by comparing them with levels that appear to be acceptable to society.

This approach is still in its infancy. Although a good amount of accident data has been collected, such data have been generated with other purposes in mind and are not directly applicable to the approach listed above. Thus it was necessary to adopt the data to the method used in this study.

For the purposes of this study, the hazards were divided into two categories. One category consists of those hazards that can cause human fatality if people are within a certain distance of the abnormal event: fire, explosion, release of radioactivity, and release of toxic gases. The second category consists of those hazards that could be injurious to human health

or the environment should an abnormal event occur – the toxic liquid wastes. These toxic liquids could result in human fatality when ingested. However, the probability of their being ingested is very low. The waste liquids most likely would reach humans only by entering a water supply. Given the time needed for this contamination to happen, measures could be taken to prevent fatalities.

Techniques were developed for quantifying the risks presented by these hazards so the risks of two disposal operations could be compared. Methods were also reviewed for defining risk levels which appear to be acceptable to society. Such yardsticks were needed to determine whether or not the accidental releases from a particular disposal operation expose society to risks which are greater than those to which it is exposed from other sources. Wherever possible, conditions were deliberately selected to bias the results in favor of on-site disposal. Again, the reasoning was that if on-site disposal were not favored under these conditions, it would not be favored at all.

In this analysis, several assumptions were made. First, employees at the site where the hazardous waste is generated, handled, or disposed of were excluded. Also excluded were persons involved in the transportation of these wastes. The rationale was that these people have freely chosen to accept the risk associated with their employment. To them, either the benefits are high or the perceived risk is comparable to that incurred in other employment. Furthermore, the risk to these people is generally minimized by the various occupational safety and health statutes and practices that have been promulgated on their behalf.

Second, several abnormal events that could not be treated quantitatively were excluded:

(1) Accidental spills due to the extra number of transfer operations (hose connections, filling drums, etc.) that would be entailed in off-site treatment.

(2) The careless attitude often associated with handling waste that is to be transported to another site, for example:

- The use of second-hand drums or slightly damaged drums for transport of corrosive waste;
- The tendency toward use of lower paid, and therefore less knowledgeable, help in handling these materials;
- The unwarranted assumption by employees that spent acid or waste acid is less strong than "fresh" acid. In one instance such an assumption led to an explosion because spent acid was put into used drums that contained residual amounts of hydrocarbon.

(3) The possible evolution of noxious gases due to pH changes during storage.

The risk factors are not amenable to mathematical treatment because of the paucity of good data. More important, however, existing training programs and safety measures at specific plant sites and transportation companies are expected to be strengthened and become more widespread. This trend will reduce the number of such abnormal events, as well as their consequences. However, it should be recognized that to the extent the above factors apply, not taking them into account represents a bias in favor of off-site processing.

Finally for purposes of comparison, waste treatment and ultimate disposal techniques at the on-site facility was assumed to be as safe as those at the off-site disposal facilities. Thus, the risks entailed in storing, transferring, processing and actually disposing of the hazardous waste on a given site could be eliminated from the calculations. These operations are performed within the boundaries of a plant site and the risks involved are essentially the same wherever the plant site is. This left the risk during transport as the principal difference between on-site and off-site treatments, or between two off-site treatments.

In general, the approach to the quantitative determination of the degree of risk posed by a hazardous waste was to calculate the probability of the threat's becoming a reality and to compare this probability with other risks to which society is exposed in its everyday life. The details of this method are presented in Appendix D and are summarized below.

Risks to Human Life. These risks stem from the possibility of a transportation accident that may release a flammable, explosive, radioactive, or gaseous toxic waste.

Methods for calculating the probable number of fatalities per person-hour of exposure were developed for each waste or hazard category. This unit of risk -- number of fatalities per person-hour of exposure -- was suggested by Starr. (See references 1 and 2 in Appendix D.) Starr also found that individuals appear to accept a risk equal to that of death by disease or accident (10^{-6} fatality/person-hour exposure) for voluntary activities (smoking, skiing, driving, etc.) and a risk about 1,000 times smaller (10^{-9}) for activities to which the individual is involuntarily exposed. This latter level of risk is approximately 10 times greater than the risk to which society is exposed from natural disasters.

Starr's analysis suffers in two respects. It fails to recognize the fact that society apparently is less willing to accept risks that may kill a large number of people, even though the frequency of occurrence is very low, than those that are more frequent but kill fewer people each time. His analysis also neglects injuries to people, which are 100 to 1000 times more frequent than fatalities but which are difficult to normalize into a single unit and for which data are unreliable and difficult to collect.

Nevertheless, Starr's unit of risk offers a number of advantages that justify its use. First, time is something that is allocated fairly uniformly to all humanity, so it is a good normalization factor for dealing with large segments of society. Second, this unit permits

one to compare risk with risk, rather than risk with some other value such as dollars. Third, it offers a useful yardstick for comparison purposes – the probability that a healthy young person will contract a fatal disease. Fourth, Starr's unit permits one to rationally compare and combine many types of risks: disease, highway accidents, sports accidents, smoking, etc. Finally, the numerical value of risk in Starr's unit corresponds well with the popular idea of whether an activity is safe or dangerous. For example, it puts into proper perspectives the comparative danger of trips to the moon and short walks to downtown shopping centers.

The exposure of individuals living along the route of travel to accidental releases of hazardous chemical wastes during transportation is an involuntary activity. According to Starr, these individuals would accept a risk equal to or less than 10^{-9} fatality per person-hour of exposure. This level corresponds to the possible loss of 1.5-3 weeks from a normal life expectancy of 60-80 years. (See Appendix D, Table D-2.)

We calculated risk levels for the flammable, explosive and radioactive wastes included in this study by using the following equation:

$$\frac{P(a) \times P(f/a) \times nLF}{HT} = \text{fatalities/person-exposure hour}$$

where:

$P(a)$ = probability of an accident per vehicle mile

$P(f/a)$ = probability of a fire (explosion or radioactive release) given an accident

n = number of trips per year

L = length of trip (miles)

F = fatalities per fire (explosion or radioactive release) = $(\pi R^2 \rho)\ P(\rho)$

H = humans exposed per year = $(2RL\rho)$

T = exposure hours per person per year = $8760\ P(\rho)$

R = kill radius (miles)

(ρ) = population density per unit area

$P(\rho)$ = probability of a person being within kill radius during accident

The derivation of this equation is described in Appendix D.

In making this calculation, an assumption was made that during the transportation of the hazardous waste, people would be exposed to the risk 24 hours per day, even though actual exposure would be only a few minutes, because one cannot predict precisely when the waste will be transported. Moreover, this is the way the public perceives the risk, as continuous rather than sporadic. A further assumption was made that every accident results in a release of the threat associated with the hazardous material (i.e., $P(f/a) = 1$) and that the probability a person living within the kill radius being there when the accident occurs is also equal to unity (i.e., $P(\rho) = 1$).

Flammable Wastes. Many of the wastes identified in this study consisted of either mixtures of combustible wastes or solutions of hazardous chemicals (e.g., DDT) in organic solvents such as xylene or toluene. A transportation accident involving either type may result in the release of combustible materials and a subsequent fire.

The method for calculating the kill radius of a fire is described in Appendix D. Briefly, we assume the spill to be 0.5 inch (1.3 cm) deep. This gives a spill diameter of 142 feet (43 meters) for a 5000-gallon (18,920 liters) truck. For typical organic fuels, a fire from this spill gives a kill radius of 185 feet (56 meters) from the center of the spill. These values were used in the general equation of risk to arrive at fatalities per person-hour exposure.

Explosions. Two types of explosions were considered: those that result from the detonation of explosive waste materials (i.e., off-spec TNT) and those that occur when a container of combustible liquid is heated by an exterior fire until the container ruptures explosively due to pressure build-up. The consequences and risks of the latter event are difficult to predict theoretically. However, descriptions of accidents in which such explosions did occur show that usually there is ample time to evacuate residents and that the casualties are limited to people within a radius of 100-200 feet (30-60 meters), usually fire fighters or plant operators. This kill radius is within the "kill" radius of a fire resulting when the entire contents of a 30,000-gallon (113,520 liter) tank car are spilled. Thus, this explosion situation would be covered by the fire kill radius.

Explosive "waste" is generally very sensitive to detonation and therefore is shipped in relatively small quantities. It can be handled "on-site" – the point where it is discovered to be bad – or can be transported to a disposal site.

Transportation is a risk that should be found acceptable by society. If one looks at the case of transporting a truckload of "off-spec" TNT along any route, the fatalities/exposure-hour are found to be around $10^{-12}n$ where n is the number of trips per year. This calculation assumes an explosion with every accident and a kill radius of 500 feet (152 meters). Thus even if explosives are transported 10 times a year and explosions occur 100 times more frequently than accidents – due to bumps on road, crackpots shooting at truck – the risk is still in the acceptable range.

Although risks to employees were not evaluated numerically, in this case a point should be made. On-site disposal – i.e., blowing up the explosive in the field – must be considered preferable to exposing society to unstable explosives. On-site disposal has only one disadvantage – air pollution – but exploding the small amount of "waste" product is insignificant compared to the large amount of "good" product that is used by society during construction, mining, etc.

Radioactive Materials. In a study of the probability of transportation accidents involving radioactive materials, Brobst* classified radioactive package damage into six classes ranging from "no break-no damage" to "large break-extreme damage." He estimated that the probability of occurrence of an accident causing "severe" damage to the package and in which radioactive material is released, i.e., P(a) x P(f/a), is 1.5×10^{-9} for barge transportation.

The risk from radioactive release was calculated using a "kill" radius of two miles (see Appendix D) and truck transportation (the worst mode) as an example. A risk of $2.8 \times 10^{-12} n$ fatalities/person-hour exposure was calculated, where n is the number of trips per year. It is obvious that this risk is very small and less than 10^{-9} as long as n is less than 357 trips per year.

Toxic Gases. A similar equation can be used to derive the risk of accidental release of toxic gaseous wastes except that a different expression has to be used for the "kill" area.

The gaseous toxic wastes identified in this study consisted mainly of nerve gas, CS, nitrogen, mustard and tear gas. These warfare gases can be shipped in various types of containers ranging in size from aircraft spray tanks that have a capacity of 1356 pounds, 615 Kg to 750-pound (340 Kg) bombs that contain 220 pounds (100 Kg) of agent, to 8-inch (20 cm) howitzer shells that contain 14.5 pounds (6.6 Kg), each and 155-mm howitzer shells that contain 6.5 pounds (3 Kg). These gases could be released by an accident leading to the rupture of the spray tank or the detonation of the ordnance. The latter event is probably of greater risk to society since the gases are dispersed over a wide area in aerosol form and these aerosols are carried by the wind for many miles.

For the purposes of this study, the dimensions of the toxic vapor cloud were assumed to be 40 miles (64 kilometers) long and 5 miles (8 kilometer) wide for a total "kill" area of 200 square miles (518 square kilometers). The risk to individuals is found to be $8 \times 10^{-12} n$ fatality per person-hour exposure for truck transportation, where n is again the number of trips per year.

This risk appears to be acceptable as long as the number of trips per year does not exceed 125. One should keep in mind that these gases would not be shipped in large tank car

*Brobst, W.A., "The Probability of Transportation Accidents," Paper presented at the 14th Annual Explosives Safety Seminar, New Orleans, La., Nov. 10, 1972.

lots without many precautions that would lower the risk even further. As mentioned earlier, however, incidents that kill large numbers of people at one time are not as acceptable to society as those that do not. Most importantly, as in the case of radioactive materials, psychological apprehension is associated with chemical warfare gases and this emotionalism makes the public perceive a higher, less acceptable risk than is really present. (At least part of this problem is being studied by HumRRO under EPA contract No. 68-03-0156.)

Risks to Human Health or the Environment. A large number of the wastes studied in this project were toxic liquid wastes which, if spilled, could cause a major water pollution problem. It is extremely unlikely, however, that heavy metal sludges or cyanide solutions would kill outright via chemical toxicity (by ingestion or skin contact). One can envision a transportation accident where one of these wastes spills directly on a person and kills him but the fatality would be related more closely to the accident than to the toxicity of the spilled chemical.

In calculating risks to human health and the environment from water pollution, some simplifying assumptions – similar to those used in the previous analysis – were made. First, although the risk of pollution from spills is inherently possible in any of the four basic waste handling and treatment steps (i.e., storage, processing, transfer, and transport), transport was considered the most important for the analysis. Risk during the other steps can be made small by the use of secondary containment dikes, excess-flow valves, automatic control devices, and leak detection systems. Furthermore, for comparison purposes, it is reasonable to assume that processing risk generally will be the same regardless of where the waste is processed.

Risks from transfer operations may vary by several orders of magnitude from one site to another because of the differences in the location, structure, and operating characteristics of the individual sites. For example, a spill at a site located in a desert area virtually precludes the possibility of the waste's reaching water. At local sites, particularly those that already exist, the probability of a spill's reaching a body of water may be anywhere from 0 to 1 (from geological considerations only). On the other hand, at any given site, the skill and care of operators and the safety measures designed into the plant will profoundly affect the probability that any spill will reach water. In one sense, therefore, it would be almost impossible to estimate risk of pollution from transfer operations without specifying a particular site. Furthermore, although this risk can be considerably higher than that posed by transport, storage, or processing, prudent precautions will alter the situation and reduce risk during transfer to a negligible level. Since such precautions are expected to be taken, and perhaps to be mandatory, it was assumed that the risk of pollution during transfer operations could be neglected.

Given the foregoing assumptions, the parameter of interest again is risk during transport. In these calculations, transport in 5000-gallon (18,920 liter) trucks was assumed. This mode of transport has the greatest frequency of accidents, involves the largest number of trips, and is the mode most commonly used.

To arrive at a measure of pollution risk, the unit chosen was the volume of water that would be needed to dilute the spilled waste to the critical concentration (that is, the minimum concentration that will produce some detrimental effect on human health or the environment). This unit of risk was suggested by Dawson, et al;* values of the critical concentration are given in the same report. In these calculations, Q_{st}, the number of milligrams of hazardous chemical spilled during transport, was estimated from the annual probability of an accident, the probability of a relase given an accident, the total volume of a shipment and the concentration of the solution shipped. The minimum value for the critical concentration C_c (in mg/liter) was chosen from Battelle's report.* The risk, measured in liters of water that could be potentially polluted per year, is thus equal to Qst/Cc. This measure of risk can be used to compare the pollution risk of two off-site treatments.

Unlike the case of risk to human life, the literature suggested no yardstick that had been used as an acceptable level of pollution – a level that society is willing to live with. However, such a yardstick may be derived from the total quantity of hazardous wastes that society voids into its waters from manufactured consumer products. Such data should become available very shortly from a study performed by Arthur D. Little, Inc., for the Environmental Protection Agency.† This catalog can be used to calculate the total quantity of waste – e.g., cyanides and fluorides – that reach water supplies through the normal use of manufactured products. The quantity of water required to dilute these wastes to the critical concentration level can then be used as a yardstick for comparing the risk of a particular transport operation.

In any case, in making an evaluation of risk, it is important to remember that hazardous materials are continually being transported in large quantities as "normal" articles of commerce. Thus, each of the specific chemical species under study is already being shipped in both large and small quantities and in many cases on a daily basis. Although the form (pure vs waste stream) may have an impact on the risk value, it will not make a radical difference. Therefore, on the basis of simple logic, one would not anticipate that many of the items listed as hazardous wastes should be too dangerous to transport to an off-site processing facility.

Legislative Framework for Controlling Hazardous Wastes

In addition to evaluating the impact of risk on the economic analysis of alternatives, it is important that one also be able to ascertain the effects of legislation. For example: What do the statutes permit or constrain? What might be needed to make an alternative viable?

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*G. H. Dawson et al, "Control Spillage of Hazardous Substances," Battelle report to FWQA No. 15090 FOZ 10/70, GPO, 1970.

†J. Berkowitz, "Catalog of Manufactured Products Having Water Pollution Potential," Final Report to EPA, Contract 68-01-0102 in preparation (1973).

How are the rules enforced? Thus, legislation pertaining to hazardous waste control at both the Federal and state levels was reviewed.

Legislation at the Federal Level. Standard sources were searched to ensure that all existing Federal statutes and regulations were identified, as well as major legislation proposed and now pending before the Congress in late 1972, which seem to relate to one or more hazardous wastes. These sources included:

- U.S. Code Annotated
- Code of Federal Regulations
- Federal Register
- U.S. Congressional and Administrative News (for legislative history stating, in some cases, the rationale underlying legal provisions)
- Official reports, for example, Toxic Substances, published by the Council on Environmental Quality in April 1971
- Articles and commentaries in law journals and environmental magazines

Whereas the statutes and official documents show Federal policies as contained in laws on the books, the articles and commentaries provide spotty but valuable information as to how effectively these laws are operating in practice.

As one might expect, legal coverage of the hazardous wastes of concern to this study varies. So do the strategies and techniques of controlling wastes. For example, neither the Hazardous Substances Act of 1966, as amended, nor The Water Pollution Control Act of 1956, as amended, focuses upon the problem of disposal. The former focuses upon the potential hazards in children's toys, such as flammability and sharp edges, while the latter focuses upon discharge of pollutants into navigable waters. However, the enforcement techniques of each are of interest: the first relies upon warning consumers by means of clear labeling, rather than, for example, upon prior testing and certification; the second becomes operative only after pollutants are dumped into waters, and provides for restrictions only after the fact, by means of permits and fines.

This inventory and analysis resulted in three products. First, it led to the development of a matrix to organize the information summary form. (See Appendix E, Table E-1). The vertical axis of the matrix lists the applicable Federal statutes; its horizontal axis, the types of information needed for this case. Each cell contains a few words or phrases describing an important aspect of the law, for example, range of applicability, strategy of control, technique of enforcement, and executing agency responsible. This matrix form of presentation does not, of course, pretend to be a lawyer's analysis of statutes, but merely an efficient means for persons to grasp quickly the legal and administrative framework as it now exists and to compare major provisions of the Acts.

The second product is an organization chart of those Federal agencies concerned with hazardous wastes (Appendix E, Figure E.1). Together with a brief description of the duties of each concerning hazardous wastes, this chart enables one to grasp at a glance the administrative means by which Federal laws are, presumably, applied. We also identified in Congress those Committees and Subcommittees having interests in hazardous waste questions.

A third product is a discussion of federal and state approaches to disposal of hazardous wastes and issues of importance in our consideration of each alternative. This discussion appears in Part 3.

Legislation at the State Level. To gain some insight into the regulation of hazardous wastes at the state level, state statutes, both existing and pending, were reviewed as were other official state documents; and a few selected legislative and executive branch officials in New Jersey and Pennsylvania were interviewed. These two states were selected for field study not only because our technical field data came from that region, but also because both states are active in developing programs to deal with problems of hazardous wastes.

In New Jersey, the magnitude of the environmental control problem in general, and the hazardous waste disposal problem in particular, is great. Northern New Jersey lying in the midst of the New York City – Philadelphia megalopolis, is densely populated with automobiles and with people. It contains a high concentration of industrial plants, especially chemical facilities. Moreover, policy-making is complicated by other factors. For example, relatively large undeveloped areas in the southern and coastal portions of the state are ripe for exploitation. In addition, New Jersey has a tradition of strong home rule: the state has more than 560 local governmental units each jealous of its prerogatives.

On the positive side, New Jersey was relatively quick to jump on the environmental-law bandwagon. In 1954, for example, New Jersey passed legislation regulating smoke emissions from industrial plants. It appears that this law was a first for a state, although the regulatory bodies did not pursue vigorous enforcement programs.

Pennsylvania, another major industrial state, has been coping for years with waste disposal problems that are made especially difficult by the geological and hydrological character of the Appalachian Mountain region. The Commonwealth has therefore enacted several comprehensive laws to control water, air, and solid waste contamination. A 1972 amendment to Pennsylvania Rules and Regulations, Chapter 75, Solid Waste Management, addresses "Hazardous Wastes" specifically and in strict fashion. (See Appendix E, Table E.6). It also has established a Department of Environmental Resources, with eight regional offices and staffs, that appears to be well organized and well led in it's administration of these laws. The Department receives important policy support from the Environmental Quality and Hearing Boards, Citizens Advisory Council, and the Joint Legislative Air and Water Pollution Control and Conservation Committee.

COMPARISON OF ALTERNATIVES

Development of the Economic Decision Maps

Because of the many variables involved in the analysis of alternatives, a series of economic decision maps was developed for use as our analytical tool. To develop these maps required the derivation of a mathematical equation that describes all the unit operating costs associated with the treatment and disposal of hazardous wastes. (See Appendix F for details.) The equation that does this is:

$$C = C_{HW} + C_{TW}M_W + C_p + C_{HR} + C_{TR}M_R + C_F$$

where:

C = Total unit cost for processing a waste.
C_{HW} = Handling cost of waste (loading, unloading, etc.)
C_{TW} = Transport cost of waste per mile.
M_W = Miles waste is transported.
C_p = Processing cost.
C_{HR} = Handling cost of residue.
C_{TR} = Transport cost of residue per mile.
M_R = Miles residue is transported.
C_F = Final disposal cost.

Many of these costs, however, are the same regardless of the site involved, assuming that the waste in question and the disposal method are the same at each site. Under these circumstances, one need consider only the net differences in cost between alternative strategies for disposing of a hazard waste. These, as it turns out, are the differences in transport cost and differences in processing cost. Therefore, the equation simplifies to:

$$C = C_{TW}(M_1 - M_2) + (C_{p1} - C_{p2})$$

where:

C = Difference in cost between two alternatives.

C_{TW} = Transport cost per mile for the waste in question.

M_1 = Miles from waste source to treatment site 1.
(For on-site disposal, $M_1 = 0$.)

M_2 = Miles from waste source to treatment site 2.

C_{p1} = Processing cost for waste in question at treatment site 1.

C_{p2} = Processing cost for waste in question at treatment site 2.

The difference in processing cost (for the same waste and treatment) is a function of the relative capacities (or throughputs) of the treatment facilities involved. Thus, the expression $C_{p1} - C_{p2}$ in the above equation can be replaced by T_1/T_2, the ratio of the throughputs at the treatment facilities being compared.

The difference in total unit cost, ΔC, can be set to zero for each processing cost ratio (or each mileage difference) and the breakeven points between alternatives can be determined by plotting $M_2 - M_1$ versus T_1/T_2. The breakeven points delineate a line that marks the boundary between conditions of transportation and processing costs that favor one alternative or an other. (See Figure 2.1.)

This gave a method of comparing alternative strategies for specific types of wastes, based on the number of waste sources within a given area and their distance from each other. As noted earlier, however, further consideration of the list of wastes led to the recognition that the important element in comparing strategies was not the waste, but the treatment process. Thus it was not necessary to compare strategies for 100 or more individual wastes or even for 35 classes of waste. Instead it was necessary only to compare strategies (on-site versus off-site disposal) for the eight treatment processes that would handle all of the hazardous wastes included in our study. This was the method adopted.

The information derived from the equation can be presented in a number of ways for purposes of deciding among strategies. (See Appendix F.) However, the information can best be displayed in the form of a decision map whose important parameters are:

- the number of sources of waste,
- the volume of waste generated by the sources, and
- the distance separating these sources.

Figure 2.2 illustrates this type of decision map. It is this type of map that is used for the discussion of the comparative economics between on-site and off-site disposal for the waste treatment processes.

Modification by Risk and Legal Factors

Once the economic difference between on-site and off-site disposal for a given strategy was calculated, the potential impact of the various risk and legal factors on that difference

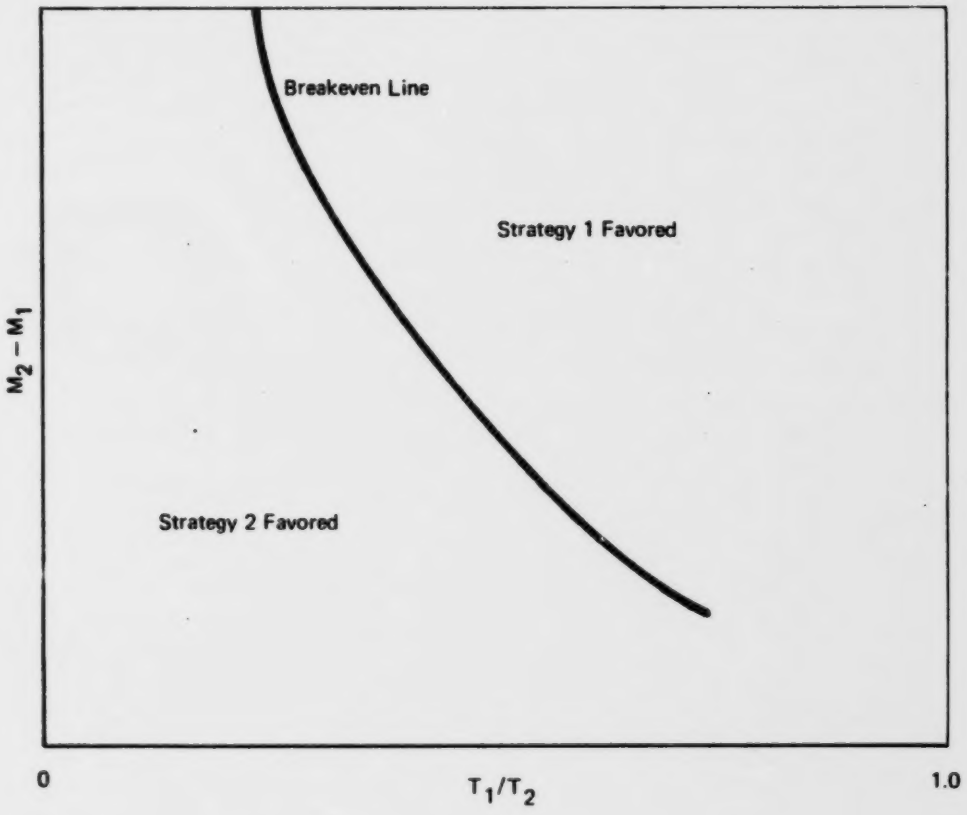

FIGURE 2.1 HYPOTHETICAL PLOT OF BREAKEVEN LINE FOR TWO STRATEGIES

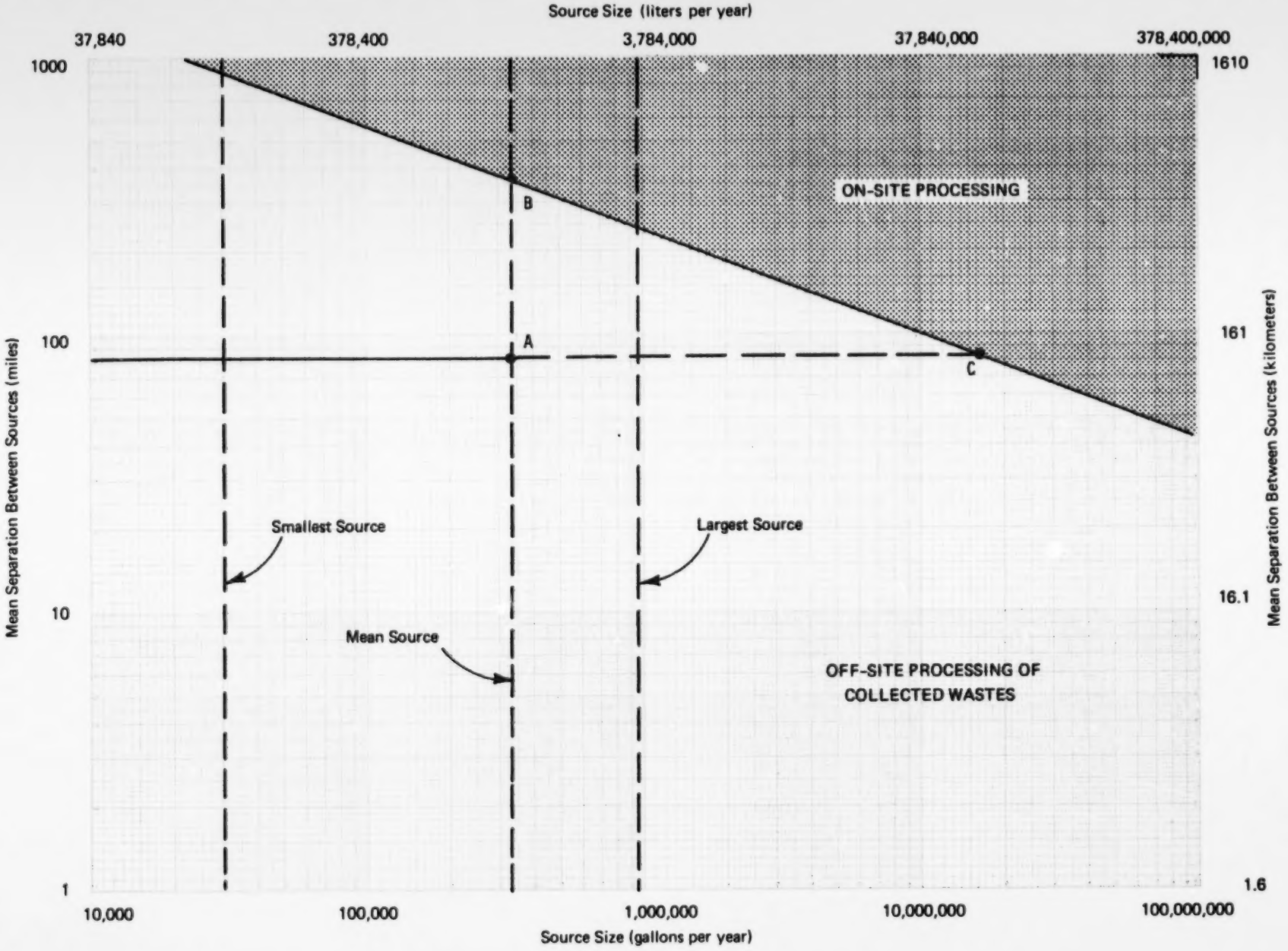

FIGURE 2.2 DECISION MAP CONCENTRATED HEAVY METALS

was determined. This could not be done directly, since the risk values were not calculated in terms of unit costs and the legal impact could not be assigned any type of numerical value. Thus, for each strategy it was ascertained whether or not the risks would be acceptable to society and whether or not there seemed to be some legal restriction that would prevent or add to the cost of a strategy.

Overall, neither the risk nor the legal factors were found to have any impact on the economics of on-site or off-site disposal.

PART 3 DISCUSSION OF RESULTS

CHARACTERIZATION OF WASTE STREAMS

The information and data that were obtained from the waste stream characterization work are given in Appendix B. Part 1 of that appendix describes the industries that are projected to have an important impact on a hazardous waste processing system: chloro-organic solvents, pesticides, paints, tanneries, metal finishing, batteries, cooling towers, chlor-alkali plants, and smelting or refining. These industries are important because they will provide a large amount of the waste streams that contain the chemicals on the hazardous waste list (Appendix A, Table A.2). A brief summary of pertinent findings is given in Table 3.1.

Looking at the specific region consisting of the two states of Pennsylvania and New Jersey, evidence was found to support the need for off-site processing here as well as in other areas in the country. Table 3.2 provides a preliminary estimate of the number of establishments, both nationally and in the local region, for selected industries. This list is not meant to represent the total number of industrial point sources in New Jersey and Pennsylvania but rather an estimate of the minimum number in those two states.

TABLE 3.1

INDUSTRIES WITH WASTES REQUIRING TREATMENT

Waste Category	Industry with Applicable Wastes	Description of Waste
Concentrated heavy metals	Pesticides	Off spec or residue from formulation; tank rinsings from applicators
	Metal finishing	Plating baths, etching solutions
Dilute heavy metal	Metal finishing	Rinse tank water
	Battery manufacture	Rinse from plate preparation
	Cooling towers	Blow down
	Chlorine production	Waste process water from chlor alkali plants
	Smelting and refining	Process water
Dilute heavy metals with organics	Tanning	Chrome tanning of hides
	Tank cleaning	Railroad or truck transport cars
	Metal finishing	Applying decorative coatings to metals
Heavy metal sludges	Tanning	Waste point source precipitates metals and then ships the sludge
	Metal finishing	
	Batteries	
	Cooling towers	
Concentrated cyanides	Metal finishing	Plating baths
Dilute Cyanides	Metal finishing	Rinse water from plating baths
Liquid organics	Chemicals	Dilute aqueous stream containing waste solvents as well as water solvents
	Pesticides	Liquid formulations
Organics with solids	Pesticides	Unused or deteriorated formulations, rinsings from applicator
	Paints	Sludge residue, wastage from spray painting
	Petroleum	Storage tank residue containing organo lead compounds
	Electronic	Capacitors with PCB

TABLE 3.2

MINIMUM ESTIMATE OF SOURCES OF HAZARDOUS WASTES*

Industry	Sources in U.S.	Sources in N. J. and Pa.
Chloro Organics Compounds	57	3
Pesticides	46	4
Paints	1700	266
Metal Plating	7000	298
Tanning	519	68
Cadmium Batteries	10	2
Chlor Alkali	29	1
Total	9361	642

*Only identified sources of wastes containing chemicals directly related to this study are included in this tabulation.

PROCESS DESCRIPTIONS

As discussed in Part 2, all of the hazardous waste materials listed in Table A.2 (except radioactive material, DOD materials, interhalogens, and explosives) can be treated by various combinations of the waste treatment processes summarized in Table 2.1.

In general, the hazardous wastes fall into three major groups: heavy metals, cyanides, and chlorinated hydrocarbons. Often, a particular industrial hazardous waste will actually fall into two of these groups and sometimes all three groups. This type of waste will require treatment by several of the processes listed in Table 2.1.

The groups of hazardous wastes may be further subdivided into subgroups – such as arsenites and arsenates and soluble and insoluble anions – which would be important in treating a very specific waste (for example, incineration of copper cyanide to recover copper). However, it has been found that most industrial hazardous waste streams contain combinations of hazardous materials that require a more general treatment system. For example, one industrial waste stream could contain arsenic, selenium, copper and hydrochloric acid. Thus, the processes illustrated in Figure 3.1 were selected on the basis of their applicability to a variety of industrial hazardous wastes rather than the treatment of a specific chemical compound.

The list of eight processes for treating hazardous wastes is not meant to be all-inclusive of the processes that might be used "off-site" at a Central Processing Facility or even of all the treatment methods that could be used "on-site" where the waste is generated. The main purpose of selecting these waste treatment systems was to allow a comparison of the total operating cost (including transportation cost) for "on-site" and "off-site" treatment systems for industrial hazardous wastes.

Several processes discussed by TRW in its reports were included, such as chrome (heavy metal) reduction and precipitation, ion exchange, activated carbon absorption, incineration of chlorinated hydrocarbons, and cyanide destruction by alkaline chlorination. Also added was sulfide precipitation of heavy metals, since the (stable) sulfides of the heavy metals are less soluble than the hydroxide and thus can be removed more efficiently from the wastewater. Other processes such as reverse osmosis and pyrolysis as described by TRW in its report were not included, because it does not appear that they would be applied widely for on-site (small-scale) processing, and these systems would involve the problem of processing secondary wastes. For specific applications, ion exchange could be used to recover many of the heavy metals, or newer methods of waste treatment – such as thermal decomposition* or hydrogen peroxide oxidation†, – are being developed for destruction of cyanide. Again, however, these systems were not included in these estimates because they are still in the development stage or would be applicable only to specific waste streams.

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*Chemical Week, Dec. 20, 1972, p. 32

†Chemical Week, Dec. 16, 1970, p. 54

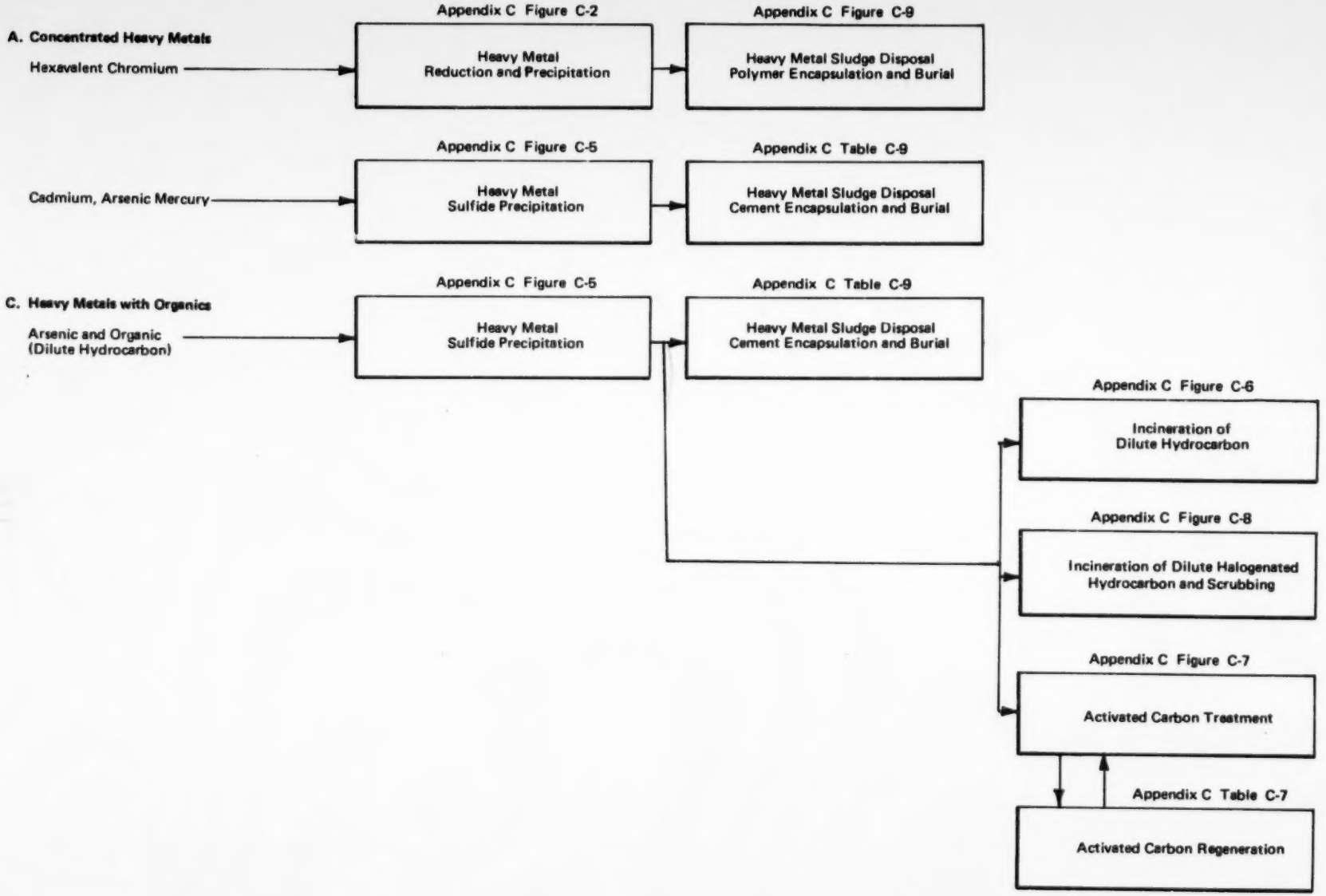

FIGURE 3.1 INTERRELATIONSHIP BETWEEN HAZARDOUS WASTES AND TREATMENT PROCESSES

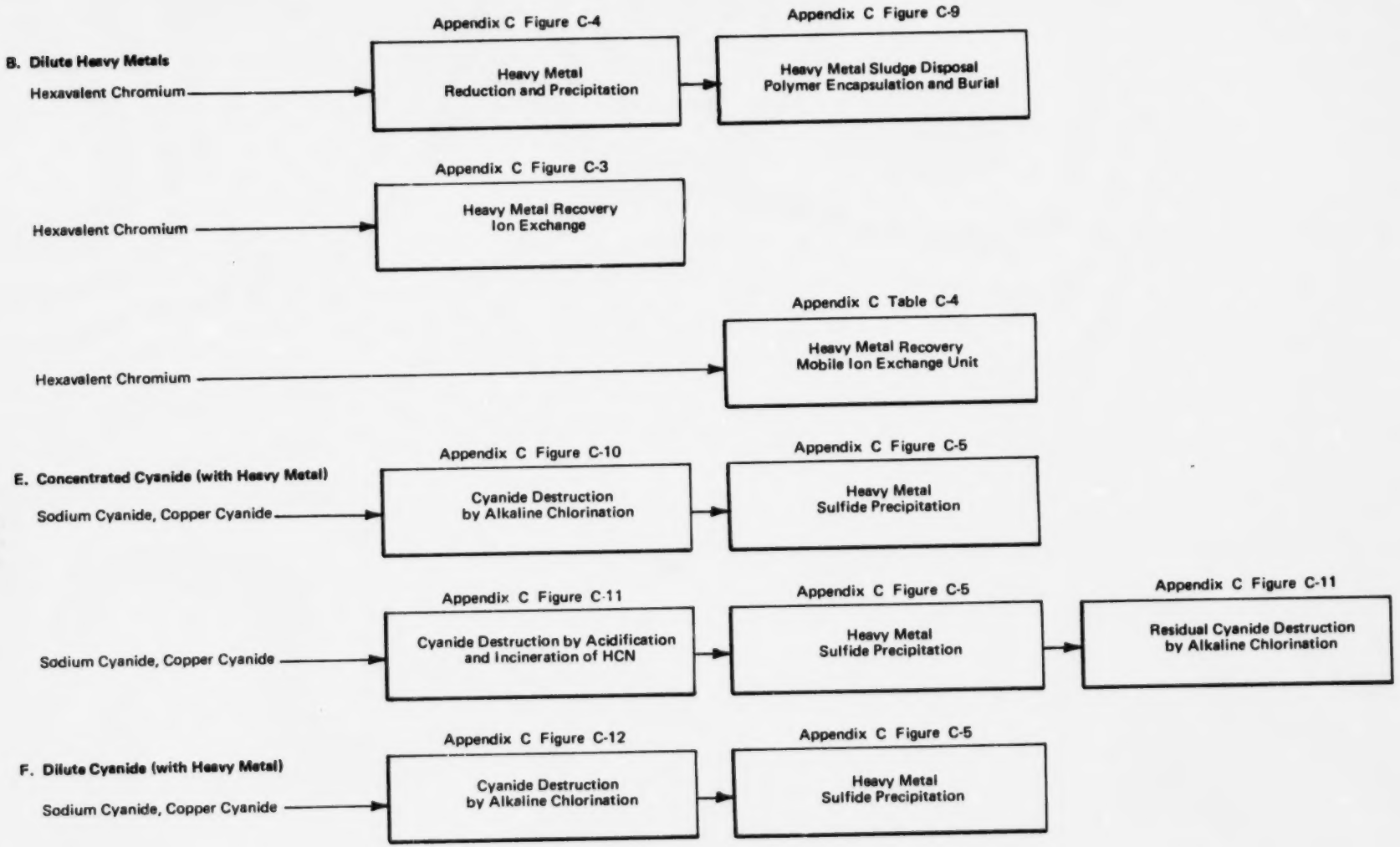
B. Dilute Heavy Metals
Hexavalent Chromium
Appendix C Figure C-4
Heavy Metal Reduction and Precipitation
Appendix C Figure C-9
Heavy Metal Sludge Disposal Polymer Encapsulation and Burial
Hexavalent Chromium
Appendix C Figure C-3
Heavy Metal Recovery Ion Exchange
Hexavalent Chromium
Appendix C Table C-4
Heavy Metal Recovery Mobile Ion Exchange Unit
E. Concentrated Cyanide (with Heavy Metal)
Sodium Cyanide, Copper Cyanide
Appendix C Figure C-10
Cyanide Destruction by Alkaline Chlorination
Appendix C Figure C-5
Heavy Metal Sulfide Precipitation
Sodium Cyanide, Copper Cyanide
Appendix C Figure C-11
Cyanide Destruction by Acidification and Incineration of HCN
Appendix C Figure C-5
Heavy Metal Sulfide Precipitation
Appendix C Figure C-11
Residual Cyanide Destruction by Alkaline Chlorination
F. Dilute Cyanide (with Heavy Metal)
Sodium Cyanide, Copper Cyanide
Appendix C Figure C-12
Cyanide Destruction by Alkaline Chlorination
Appendix C Figure C-5
Heavy Metal Sulfide Precipitation

FIGURE 3.1 (Continued)

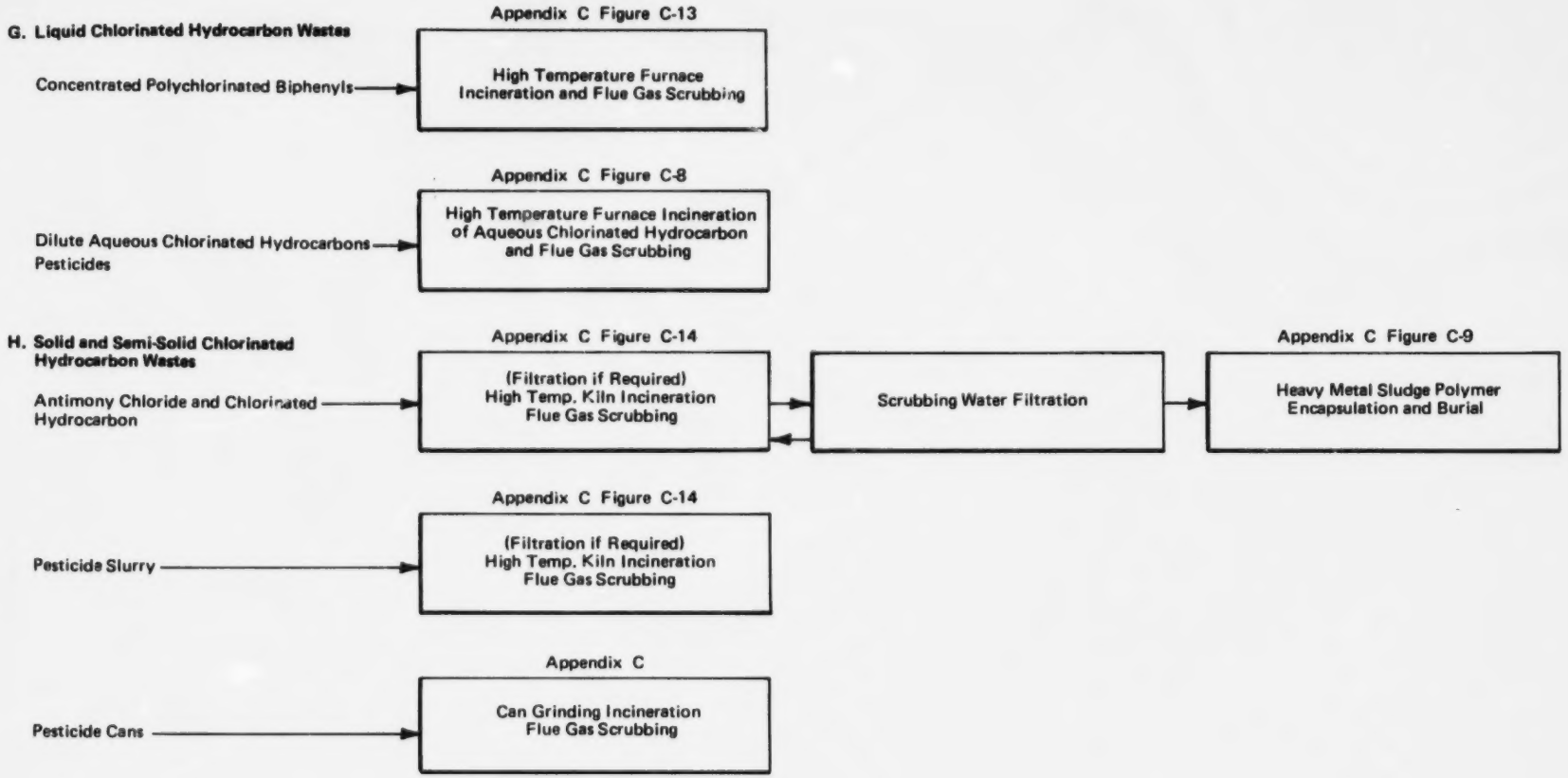
G. Liquid Chlorinated Hydrocarbon Wastes
Concentrated Polychlorinated Biphenyls
Appendix C Figure C-13
High Temperature Furnace Incineration and Flue Gas Scrubbing
Dilute Aqueous Chlorinated Hydrocarbons
Pesticides
Appendix C Figure C-8
High Temperature Furnace Incineration of Aqueous Chlorinated Hydrocarbon and Flue Gas Scrubbing
H. Solid and Semi-Solid Chlorinated Hydrocarbon Wastes
Antimony Chloride and Chlorinated Hydrocarbon
Appendix C Figure C-14
(Filtration if Required) High Temp. Kiln Incineration Flue Gas Scrubbing
Scrubbing Water Filtration
Appendix C Figure C-9
Heavy Metal Sludge Polymer Encapsulation and Burial
Pesticide Slurry
Appendix C Figure C-14
(Filtration if Required) High Temp. Kiln Incineration Flue Gas Scrubbing
Pesticide Cans
Appendix C
Can Grinding Incineration Flue Gas Scrubbing

FIGURE 3.1 (Continued)

Treatment of Heavy Metal Wastes

Heavy metals may be removed from wastewater by precipitation as either the hydroxide or the sulfide. The hydroxide (or sulfide) sludge is settled from the wastewater and concentrated by filtration and centrifugation. To the extent that these sludges are being landfilled directly, this approach could allow relatively easy reintroduction into the environment through natural leaching. For adequate treatment these sludges should be encapsulated before being landfilled to minimize their leaching back into the environment. Therefore, encapsulation and landfill burial of these sludges have been included as part of our waste treatment scheme.

Concentrated Heavy Metals. All of the heavy metals may be precipitated as the sulfides, which in general are much less soluble than the hydroxides and, therefore, can be removed more completely from the wastewater. (Insoluble heavy metal compounds could be encapsulated in polymer or concrete, without further treatment, and be buried.)

Unfortunately, chromium sulfide hydrolyzes to the hydroxide when exposed to air, so it was assumed that this heavy metal would be precipitated as the hydroxide in the waste treatment processes. In addition, prior to precipitation, the hexavalent chromium must be reduced to the trivalent chromium. This can be done by a number of reducing agents, including ferrous sulfate or sulfur dioxide. In industry the most widely used reducing agent for this purpose is sulfur dioxide. (The ferrous sulfate produces a more voluminous precipitate when the chromium is precipitated as the hydroxide.) Following reduction to its trivalent state, the chromium is precipitated as the hydroxide, generally using lime as the precipitating agent. This hydroxide sludge would be encapsulated and buried in a manner similar to that used for the sulfide sludges. If there were a market for the chromium hydroxide, the hydroxide could be recycled as an alternative to encapsulation and landfill, but presently it appears more economical to produce chrome from the ore than to try to recover it from these sludges. Chrome wastewaters can be treated by this method in either a batch or a continuous system. For small volumes it is usually batch treatment, whereas in very large volumes it is continuous.

When the chromium is in a dilute solution (such as plating bath rinse) it is often possible to recover the chromium by ion exchange as an alternative to disposing of the chrome as a waste. In this situation both chromic acid and demineralized water are recovered for reuse.

The possibility of recovering chromic acid from chromium plating wastewater using a mobile ion-exchange unit was also examined. In this case deionized water would be available on-site, but the chromic acid would not be.

Ion exchange is not generally used for recovery of concentrated chromic acid because the resin would be quickly exhausted, large amounts of regenerant would be required, and very little demineralized water would be recovered.

Heavy Metal Wastes Containing Organics. When the heavy metal waste stream also contains organics or hydrocarbons, it will be necessary to treat the stream for this material after heavy metal precipitation but prior to discharge. These organics may be removed by activated carbon treatment or simply by incinerating the waste stream. If, in addition to the hydrocarbons, the waste stream contains halogens (such as chlorine) or salts such as sodium sulfite it would be necessary to scrub the flue gas after incineration of the waste stream.

If activated carbon were used for final treatment to remove the organic material, the activated carbon would have to be regenerated or disposed of. In the proposed process scheme, "on-site" regeneration of this activated carbon was assumed.

Encapsulation and Burial of Heavy Metal Sludges. The hydroxide sludges are relatively stable and could be encapsulated for burial by any of the techniques shown in Appendix C. Some of the sulfides have a high enough vapor pressure (e.g., arsenic sulfide) so they would have to be encapsulated by one of the cold encapsulation techniques (e.g., cement encapsulation) rather than the hot melt technique using scrap polymer or asphalt.

In each of the encapsulation techniques the heavy metal sludge is mixed with the binding agent (cement, molten asphalt or polymer, whenever binder is used by private companies in this business) and then cast in waste drums for burial.

Treatment of Cyanide Wastes

Many techniques may be used to destroy cyanide wastes. Among these are hypochlorite, alkaline chlorination and hydrogen peroxide oxidation or thermal oxidation. The most widely used of these systems in U.S. industry for complete destruction of the cyanide is alkaline chlorination, so this method has been used as a basis for our process costing. As in the case of chrome wastewater, small volumes are treated in continuous systems.

If the cyanide wastewater also contains heavy metals, heavy metal treatment would be required after the cyanide destruction.

Treating a concentrated cyanide waste by alkaline chlorination requires large quantities of the chlorine and caustic. Therefore the operating cost for an alternative cyanide treatment method was estimated, where the concentration of cyanide would be substantially reduced in the first step by acidification, the HCN gas then volatilized and incinerated, and the residual cyanide destroyed by alkaline chlorination in the second step. If heavy metals were present, they would be precipitated between these two steps to take advantage of the reduced amount of alkali required in the alkaline chlorination second step. (The wastewater would be alkaline after heavy metal precipitation.)

Disposal of Chlorinated Hydrocarbons

The chlorinated hydrocarbon wastes occur as liquids, slurries, solids and aqueous solutions.

The most resistant of these chlorinated hydrocarbons can be destroyed by incineration at temperatures of 2500-2800 F. (1370–1536 C.) In order to reach these combustion temperatures, auxiliary fuel (gas or oil) must be used. In the proposed treatment scheme fuel oil is mixed with the liquid chlorinated hydrocarbons (containing no solids). This mixture would be fed to the furnace just as would be the liquid chlorinated hydrocarbons, but more fuel would be required to vaporize and heat the water in the solution. The flue gas is cooled in a spray chamber, and the by-product hydrogen chloride is then scrubbed from the flue gas in a scrubbing system using a Venturi first stage and a packed tower second stage with lime hydrate as the absorbent. The dilute waste calcium chloride solution would be discharged to an appropriate receiving body of water.

If the chlorinated hydrocarbon were in the form of a slurry, the solid and liquid phases would be separated prior to incineration. The liquid phase would be mixed with fuel oil and fed to a rotary kiln through an atomizing nozzle while the solid phase was charged directly to the kiln. Solid chlorinated hydrocarbons would be fed directly to the kiln.

ECONOMICS OF WASTE TREATMENT

This chapter deals with the economics of waste treatment processes. Appendix C, which provides additional details of the economics, also shows flow sheets of each of the processes described above.

In estimating the cost for "on-site" treatment of hazardous wastes, these costs were based on large individual sources. The rationale was that if it were not more economical for a large individual source to treat the waste "on-site" than at a central processing facility, it would be even less economical for "on-site" treatment for smaller sources of the hazardous waste.

The estimates of capital investment and operating cost are calculated for specific waste streams and treatment methods. A change in the size or composition of the waste stream or the treatment method could greatly affect capital and treatment costs.

If it is assumed that the same treatment scheme is used both for "on-site" treatment and treatment at the Central Processing Facility, the major cost factors affected will be those related to scale: depreciation, maintenance, taxes (capital investment related), and labor and administrative overhead (labor related). It was assumed in these estimates that chemical and utility costs would be the same for both "on-site" and at a Central Processing Facility, although the unit costs for chemicals and utilities would probably be less at the Central Facility. Thus, these estimates were biased in favor of "on-site" treatment. Although the capital investment and labor-related costs per unit of treated waste will be lower for the Central Facility than for "on-site" treatment, transportation cost must be added. The reduction in labor- and capital-related costs is traded off against transportation cost in the Decision Map Analysis.

Table 3.3 summarizes capital investment and operating costs for the eight major treatment processes (See Appendix C for details).

Treatment of Concentrated Heavy Metals (A)

Although the precipitation and removal of the heavy metals as hydroxides would be less costly than their precipitation as the sulfide (18¢ vs 20¢/gallon [4.7–5.2¢/liter] of wastewater), sulfide precipitation would be preferable for some of the metals (e.g., arsenic, mercury) to obtain maximum removal. The sulfide process is more expensive because of the need to remove residual H_2S prior to discharge of the wastewater.

To the cost of the heavy metal removal must be added the cost of heavy sludge disposal (Process D) and, if organics are present, the costs for adequate wastewater treatment, Process C (Aqueous Organic Treatment).

TABLE 3.3

CAPITAL INVESTMENT AND OPERATING COSTS FOR WASTE TREATMENT PROCESSES[1]

Process	Fig. No.[1]	Treatment[2] System Capacity (gals/day)	Fixed Capital Investment ($1000)	Total[3] Operating Cost (¢/gal)	Scale Dependent Operating Costs[3] Investment (¢/gal.)	Scale Dependent Operating Costs[3] Labor (¢/gal.)
A. Concentrated Heavy Metals[4]						
SO_2 Reduction and Precipitation	C.2	2,000	170	18.0 (4.8)	10.0 (2.6)	7.0 (1.8)
Sulfide Precipitation	C.5	2,000	200	20.0 (5.3)	11.0 (2.9)	7.0 (1.8)
B. Dilute Heavy Metals[4]						
SO_2 Reduction and Precipitation	C.4	10,000	55	1.0 (0.3)	0.6 (0.2)	0.3 (0.1)
Ion Exchange	C.3	10,000	68	1.1 (0.3)	0.7 (0.2)	0.3 (0.1)
C. Organics with Heavy Metals[5]						
Incineration of Aqueous Organics	C.6	2,000	82	8.0 (2.1)	4.6 (1.2)	0.8 (0.2)
Incineration of Chlorinated Aq. Organics	C.8	2,000	170	17.0 (4.5)	10.0 (2.6)	5.0 (1.3)
Activated Carbon Treatment of Aq. Organics	C.7	2,000	64[6]	39.0[7] (10.3)	0.01 –	0.04 –
Activated Carbon Regeneration	C.7	2,000	300	32.0[8] (8.5)	15.0 (4.0)	10.0 (2.6)

1. Appropriate back-up data and estimates given in Appendix C
2. Values in metric system are: 1,000 gals/day = 3,784 liters/day
   2,000 gals/day = 7,568 liters/day
   3,000 gals/day = 11,352 liters/day
   10,000 gals/day = 37,840 liters/day
3. Values in parentheses are ¢/liter
4. Does not include heavy metal sludge disposal (D)
5. Does not include heavy metal precipitation (A) or sludge disposal (D)
6. Does not include activated carbon regeneration
7. Includes activated carbon cost (regeneration)
8. This equals 10¢/pound (22¢/Kg) activated carbon regenerated

TABLE 3.3 (Continued)

CAPITAL INVESTMENT AND OPERATING COSTS FOR WASTE TREATMENT PROCESSES[1]

Process	Fig. No.[1]	Treatment System Capacity[2] (gals/day)	Fixed Capital Investment ($1000)	Operating Costs[3] (¢/gal Sludge)	Operating Cost[3, 9] (¢/gal Wastewater)
D. Heavy Metal Sludge Disposal[9]					
Cold Encapsulation	Table C.9	2,000	–		
Company A	Table C.9	2,000	–	8-10 (2.1-2.6)	3-4 (0.8-1.1)
Company B	Table C.9	2,000	–	3-12 (0.8-3.2)	2-5 (0.5-1.3)
Cement	Table C.9	2,000	–	25 (6.6)	11 (2.9)
Hot Melt Encapsulation	Fig. C.9	2,000	21	10 (2.6)	4 (1.1)

Process	Fig. No.[1]	Treatment System Capacity[2] (gals/day)	Fixed Capital Investment ($1000)	Total[3] Operating Cost (¢/gal)	Scale Dependent Operating Costs[3] Investment (¢/gal)	Scale Dependent Operating Costs[3] Labor (¢/gal)
E. Concentrated Cyanide[10]						
(with Heavy Metals)						
Alkaline-Chlorination	Fig. C.10	1,000	100	16.6 (4.4)	11.2 (3.0)	3.3 (0.9)
Acidification-Alkaline Chlorination	Fig. C.11	1,000	150	24.1 (6.4)	16.8 (4.4)	6.6 (1.7)
F. Dilute Cyanide[10]						
(with Heavy Metals)						
Alkaline Chlorination	Fig. C.12	1,000	95	12.0 (3.2)	10.8 (2.9)	1.3 (0.3)
G. Liquid Chlorinated Hydrocarbons[11]	Fig. C.13	3,000	1,040	83.3 (22.0)	39.0 (10.9)	4.4 (1.1)
H. Chlorinated Hydrocarbon Slurries or Solid Chlorinated Hydrocarbons	Fig. C.14	3,000	1,260	96.3 (25.4)	47.2 (12.5)	8.8 (2.3)

9. For 2000 gals/day (7,568 liters/day)
10. Does not include heavy metal treatment
11. Aqueous chlorinated Hydrocarbons are included under Process (C) organics with heavy metals.

Dilute Heavy Metals (B)

In addition to heavy metal removal by precipitation, dilute heavy metals may be removed (and recovered) by ion exchange. The cost for both of these methods is nearly the same (Table 3.3). In the reduction-precipitation method, however, a chrome sludge must be disposed of, whereas in the ion exchange system, sodium and calcium sulfate must be disposed of.

Organics with Heavy Metals (C)

If the wastewater containing heavy metals also contains organics (chlorinated or non-chlorinated hydrocarbons), these organics must be treated following heavy metals removal. If the hydrocarbon were not halogenated (chlorinated), the aqueous organic stream could merely be mixed with fuel (oil) and burned. The cost would be about 8¢ per gallon (2¢/liter) of wastewater as shown in Table 3.3. If a halogen is present, the flue gas from this combustion must be scrubbed to remove the halogen before it is discharged to the atmosphere, which would increase the cost to 17¢ per gallon (4.5¢/liter). If waste fuel oil were available at no cost, the incineration cost for both of these processes would be reduced by about 2¢ per gallon (0.5¢/liter) of wastewater. The cost of incinerating dilute wastewaters would be nearly independent of hydrocarbon concentration until concentrations reached about 25% by weight, when the fuel value of the hydrocarbon would start to reduce the incineration cost. (For chlorinated hydrocarbons, the cost would increase with increasing concentrations because of increased scrubber size and alkali requirements.)

Activated carbon absorption was also costed as a method for treating aqueous organic wastes, but for the concentration of organics in the estimate (2% by weight) the amount of activated carbon required makes this a very expensive process (39¢/gal. [10¢/liter] wastewater for carbon absorption vs 17¢/gal. [4.5¢/liter] wastewater for incineration of aqueous chlorinated hydrocarbon). If the concentration of the organic material in the wastewater were instead 0.5% by weight (5,000 ppm), the cost of activated carbon treatment including carbon regeneration) would be about 15¢ per gallon (4¢/liter) of wastewater.

Heavy Metal Sludge Disposal (D)

At least two companies (Companies A and B) encapsulate waste sludges in a proprietary binding material for burial, and their general price range for this service has been included in Appendix C, Table C.9.0. In addition, very cursory estimates have been made of the cost of encapsulating these heavy metal sludges in cement (cold encapsulation) and in a hot melt of asphalt or waste polymers.

In cement encapsulation, the amount of cement that must be added to bind the water in the sludge (at 20% solids) would increase the volume of the sludge from 1.0 volume to 1.65 volumes. The cement and sludge would be mixed in a rented truck or portable type

cement mixer. The asphalt or polymer encapsulation, on the other hand, would reduce the volume of sludge through evaporation of the water in the sludge. The lesser volume of encapsulated sludge in asphalt encapsulation, when it can be used, results in a lower landfill burial cost. The cost of labor and binding material would also be less for asphalt encapsulation than for cement encapsulation (Table C.9).

Concentrated Cyanide Waste (E)

The cost of treating a concentrated cyanide waste in one step by alkaline-chlorination was compared with a two-step process in which the cyanide solution is first acidified to liberate HCN (which is incinerated) and then treated for residual cyanide by alkaline chlorination. Despite the advantage of lower chemical consumption (and subsequent sodium salts in the effluent), the cost for the two-stage treatment of the cyanide wastewater is greater than that of the single-stage alkaline chlorination. This increase is due both to higher capital investment and to higher labor requirements for conducting a two-stage reaction compared with a single-stage reaction.

Often these cyanide wastes also contain heavy metals that require treatment. The cost of heavy metal treatment is not included in this estimate, and would have to be added to arrive at the total wastewater treatment cost.

Dilute Cyanide Waste

Dilute cyanide wastewater would be treated by alkaline chlorination. As before, the treatment cost estimated in Table 3.3 does not include any additional heavy metal treatment that would be required.

Liquid Chlorinated Hydrocarbons

The cost of treating liquid chlorinated hydrocarbons will depend on several factors, the most important of which are chlorine content, heat value and, of course, system capacity. More than half the capital investment for this system is for scrubbing the HCl gas by-product, and the size of the scrubbing system will be affected by the chlorine content of the chlorinated hydrocarbon. About half the operating cost (including capital charges) is related to the capital investment. Scrubbing alkali and fuel account for most of the remainder. For chlorinated hydrocarbons with greater heat values, the requirement for auxiliary fuel is reduced. Also, if a waste fuel (e.g., motor oil) could be used, this would also reduce the operating cost considerably.

It has been assumed that the dilute calcium chloride solution (less than 1 percent $CaCl_2$) could safely be discharged to some body of water. If this were not possible, it might be necessary to recycle the calcium chloride solution several times and then recover the calcium chloride through spray drying. This would, of course, increase the cost of disposal.

Chlorinated Hydrocarbon Slurries and Solids

The basic differences between this system and the other for handling liquid chlorinated hydrocarbons are that a rotary kiln would replace the furnace for burning the waste and a filtration system would be required for separating the liquid and solid phases. The solids could be fed directly to the kiln while the liquid phase would be mixed with fuel oil and fired into the kiln through an atomizing burner nozzle. The capital and operating costs for this system are slightly higher than those for the liquid chlorinated hydrocarbons alone. Because of the solids handling problem in addition to the liquid incineration, labor requirements for this system would be greater than for the liquid alone.

Mobile Incinerator for Chlorinated Hydrocarbons

A cursory evaluation of using a portable incinerator to dispose of chlorinated hydrocarbons indicates there would be no real economic advantage because additional storage capacity would be required on-site, there would be a large periodic requirement for utilities on-site (cooling water, fuel oil, power) and a very large utilization factor would be required to offset the additional investment for transport equipment.

A mobile system for the disintegration and incineration of empty pesticide cans is described in Appendix C.

Interhalogens

These compounds are expected to occur only in extremely small quantities either on-site or at a regional off-site facility. They would be incinerated with off-gas scrubbing in exactly the same manner as chlorinated hydrocarbons; a fuel rich system (oil or propane/butane) would be used to provide a reducing atmosphere to permit scrubbing the resultant halogen acids with caustic.

Mobile Waste Disposal Systems

The biggest cost item with respect to on-site disposal is most often the high fixed charges associated with the low throughput in expensive waste treatment equipment. Waste treatment equipment on a mobile van could be, say, 4 times larger but use only one-fourth the time at a given site to achieve economies of scale. (If the 0.6 exponent is used, this example calculates to $4^{0.6} \div 4 = 57.5\%$ of the original investment.) This approach was considered for heavy metal wastes requiring ion exchange, chlorinated hydrocarbons requiring incineration and scrubbing, and insecticide can destruction and decontamination.

With respect to ion exchange, it was found that the cost of the large waste retention pond, to permit holding liquor for say one month for one week's treatment time at four

times the normal rate, plus the extra fixed charges on tractor and trailer for the mobile unit more than offset the savings that accrue from using the equipment only one week per month. (Appendix C shows our cost estimates for such a system.)

A mobile unit for burning dilute chlorinated hydrocarbons is even less attractive than the ion exchange unit because of the need for enclosed tanks to retain the waste (compared to the cheaper ponds considered for ion exchange treatable waste).

A portable, insecticide-can, destruction and decontamination system could be economic to the point of even paying for itself (zero destruction cost per can) depending on initial cost of the unit and the net sales price of the scrap iron generated. A $300,000 portable unit operating at the rate of one can per minute could break even at $30/ton ($27/metric ton) net scrap value (Appendix C, summarizes the factors in this estimate.) Unfortunately, the scrap iron market varies over a wide range, $10-40/ton ($9–36/metric ton) and requires contracts for delivering large tonnages so it is difficult to draw any economic conclusions from our cost estimates.

ECONOMIC DECISION MAPS

On-site versus Off-site

The decision map provides the mechanism for comparing on-site to off-site alternatives for each of the eight waste categories described earlier. The basic data on which the comparison was based for each category are shown in Table 3.4. The scale-dependent processing cost shown in column (4) includes only labor and capital related costs, which depend on the scale of the processing operation. Chemical and utility costs are independent of processing scale on the unit waste basis used here.

The decision maps for the eight waste categories are shown in Figures 3.2 through 3.9. (Two decision maps are required under Category 4, Heavy Metal Sludges, to show the two alternative processes, encapsulation by asphalt or cement.)

The decision map for concentrated heavy metals, Figure 3.2, is representative of the others and will be discussed in detail. Point A on the map best represents the sample of sources obtained in field work. This point is defined by the mean separation between sources and the mean source size. The position of Point A on the map shows whether the on-site or off-site processing alternative is economically preferable. Here Point A lies comfortably within the OFF-SITE region of the map, and the off-site processing of collected wastes is recommended.

The vertical lines corresponding to the smallest and largest sources in the sample are also shown for perspective.

Two other points on the map are of interest. Point B defines the separation between sources that would be required if on-site processing were to be feasible with sources the same size as the sample mean. For concentrated heavy metals, this change-of-strategy separation is 360 miles (579 kilometers), whereas the actual value is 81 miles (130 kilometers). Point C defines the source size at which on-site processing becomes feasible for sources separated by the sample mean separation. For concentrated heavy metals, this size is 16 million gallons (60 million liters) per year (gpy), compared to a sample mean of 325,000 gpy (1,230,000 liters per year) and a sample maximum of 950,000 gpy (3,595,000 lpy.) Clearly, off-site processing is preferable for these wastes by a large margin.

With one exception, the decision maps for each waste category lead to the conclusion that off-site processing is preferable. The exception, dilute heavy metals (Figure 3.3), deserves special discussion. The sample data point falls in the ON-SITE region of the decision map. The map also shows that for off-site processing to be feasible, the sources would have to be 34 miles (55 kilometers) apart (instead of the 75 miles (121 kilometers) shown by the sample) or have a mean size of 100,000 gpy (378,400 lpy) (instead of the 760,000 gpy (2,876,000 lpy) shown by the sample). The implications of these values are discussed later.

TABLE 3.4

SUMMARY OF WASTE STREAM DATA[1]

	Table Reference in Appendix B	Number of Sources	Geographical Area in Which Sources Were Found (sq. miles)	Scale Dependent Processing Cost (¢/gal at Standard Basic Capacity)	Source Sample Size Characteristics			Mean Separation Between Sample Sources (miles)
					Smallest (gpy)	Mean (gpy)	Largest (gpy)	
1. Concentrated Heavy Metals	B.2.A	9[2]	60,000 sq. miles	16¢/gal @ 2000 gpd	30,000	325,000	940,000	81
2. Dilute Heavy Metals	B.2.B	14	300,000	1.0 @ 10,000 gpd	3,000	760,000	60,000,000	73
3. Dilute Heavy Metals with Organic Contamination	B.2.C	9 2	80,000	3.8 @ 10,000 gpd	25,000 100,000,000	740,000 200,000,000	3,500,000 300,000,000	94 –
4. Heavy Metal Sludges								
a. Asphalt encapsulation	B.2.D,B	8[3]	60,000	7.3 @ 830 gpd	2,000	525,000	3,500,000	97
b. Cement encapsulation	B.2.D	6[4]	80,000	1.2 @ 830 gpd	4,000	45,000	130,000	115
5. Concentrated Cyanides	B.2.E	11[5]	150,000	25.5 @ 1000 gpd	6,000	140,000	700,000	115
6. Dilute Cyanides	B.2.F	7	80,000	14.5 @ 1000 gpd	8,000	250,000	1,000,000	108
7. Liquid Chlorinated Hydrocarbons	B.2.G	26	500,000	43.5 @ 3000 gpd	10,000	160,000	670,000	140
8. Chlorinated Hydrocarbons and Heavy Metal Slurries	B.2.H	20	250,000	56 @ 3000 gpd	1,000	225,000	1,000,000	115

1. For conversion to metric system use following factors:
   1 square mile = 2.59 square kilometers
   1 gallon = 3.784 liters
   1 mile = 1.609 kilometers
2. Waste A-10, a sludge, omitted from analysis.
3. Includes Wastes D-6, D-7, D-9 and sludges from dilute heavy metal wastes B-2, B-6, B-7, B-11 and B-13 with sludge volume estimated at 7.5 gallons (281 liters sludge per 10,000 gallons (37,840 liters) waste.
4. Includes Wastes D-1 through D-5 and D-8.
5. Waste E-3, a sludge, omitted from analysis.

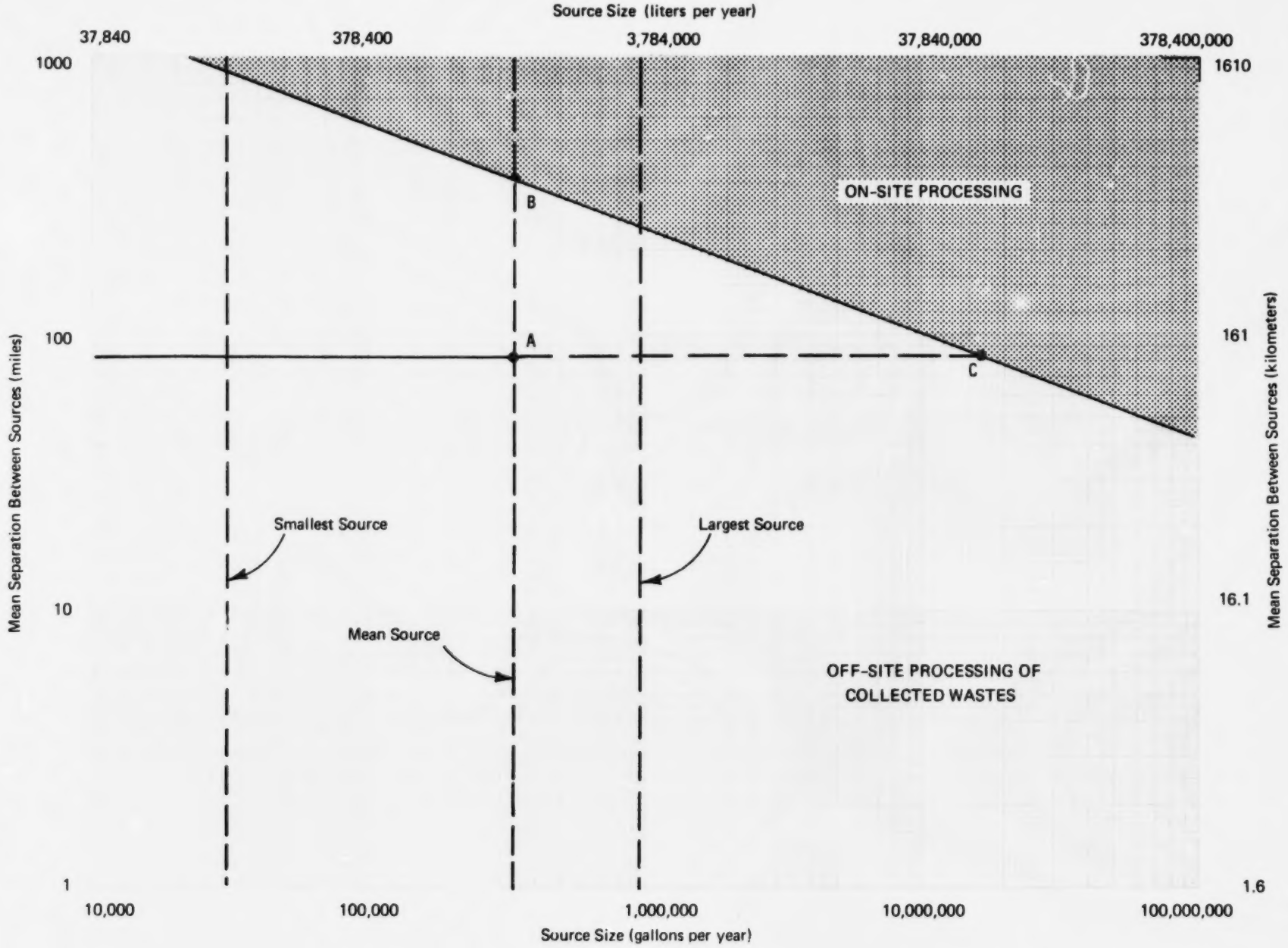

FIGURE 3.2 DECISION MAP CONCENTRATED HEAVY METALS

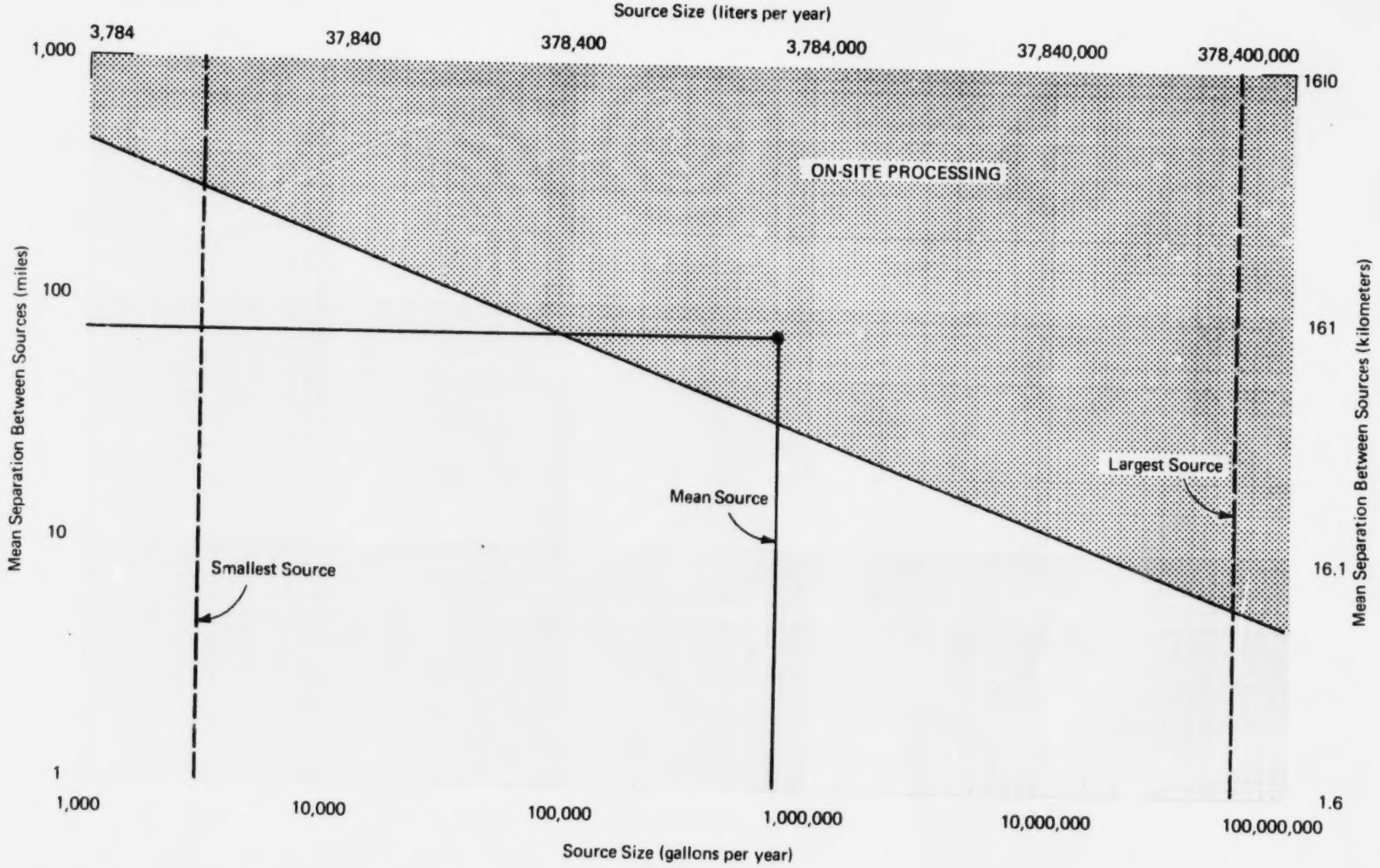

FIGURE 3.3 DILUTE HEAVY METALS

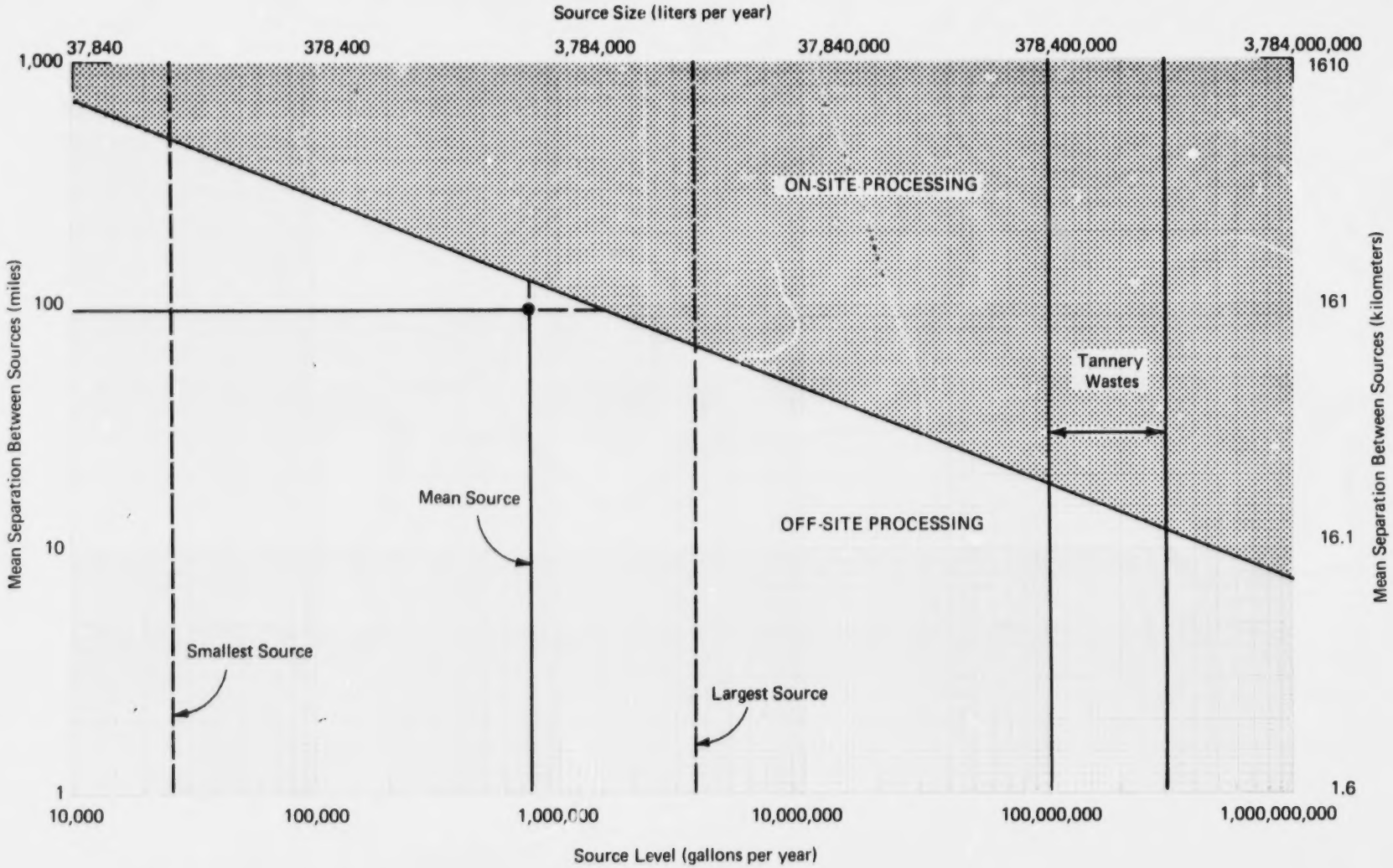

FIGURE 3.4 DILUTE METALS WITH ORGANIC CONTAMINATION

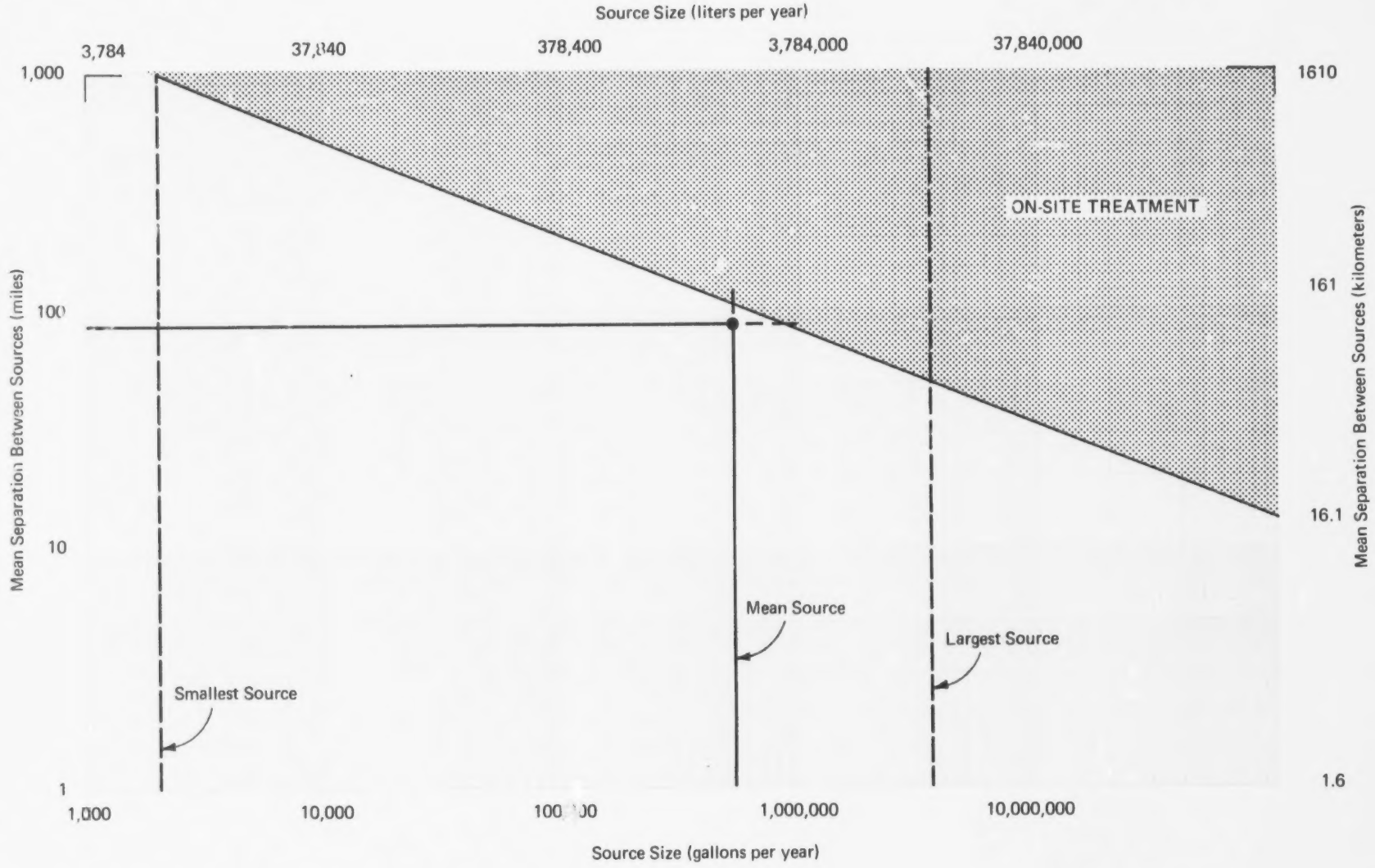

FIGURE 3.5a ASPHALT ENCAPSULATION OF HYDROXIDE SLUDGES

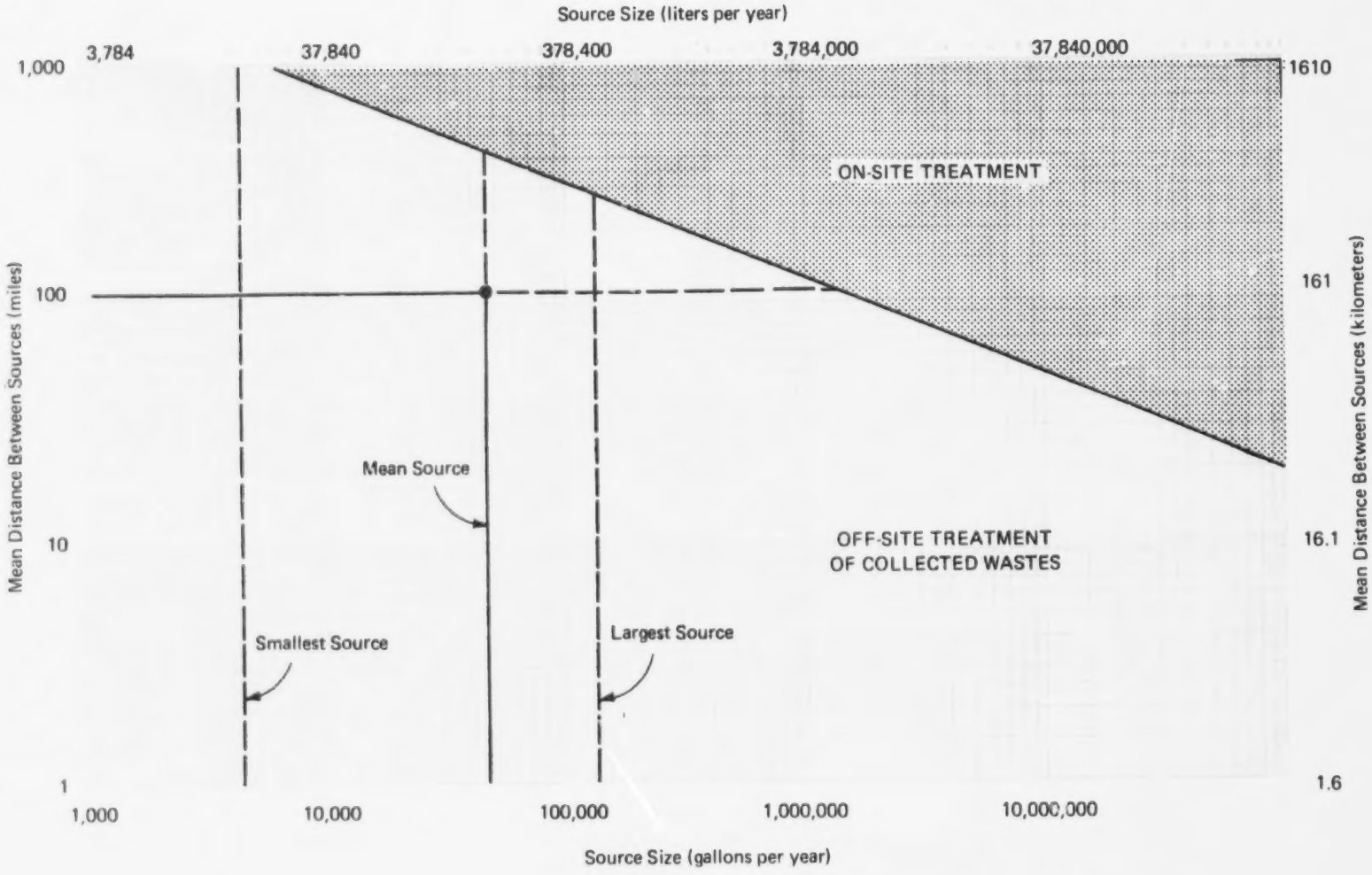

FIGURE 3.5b CEMENT ENCAPSULATION

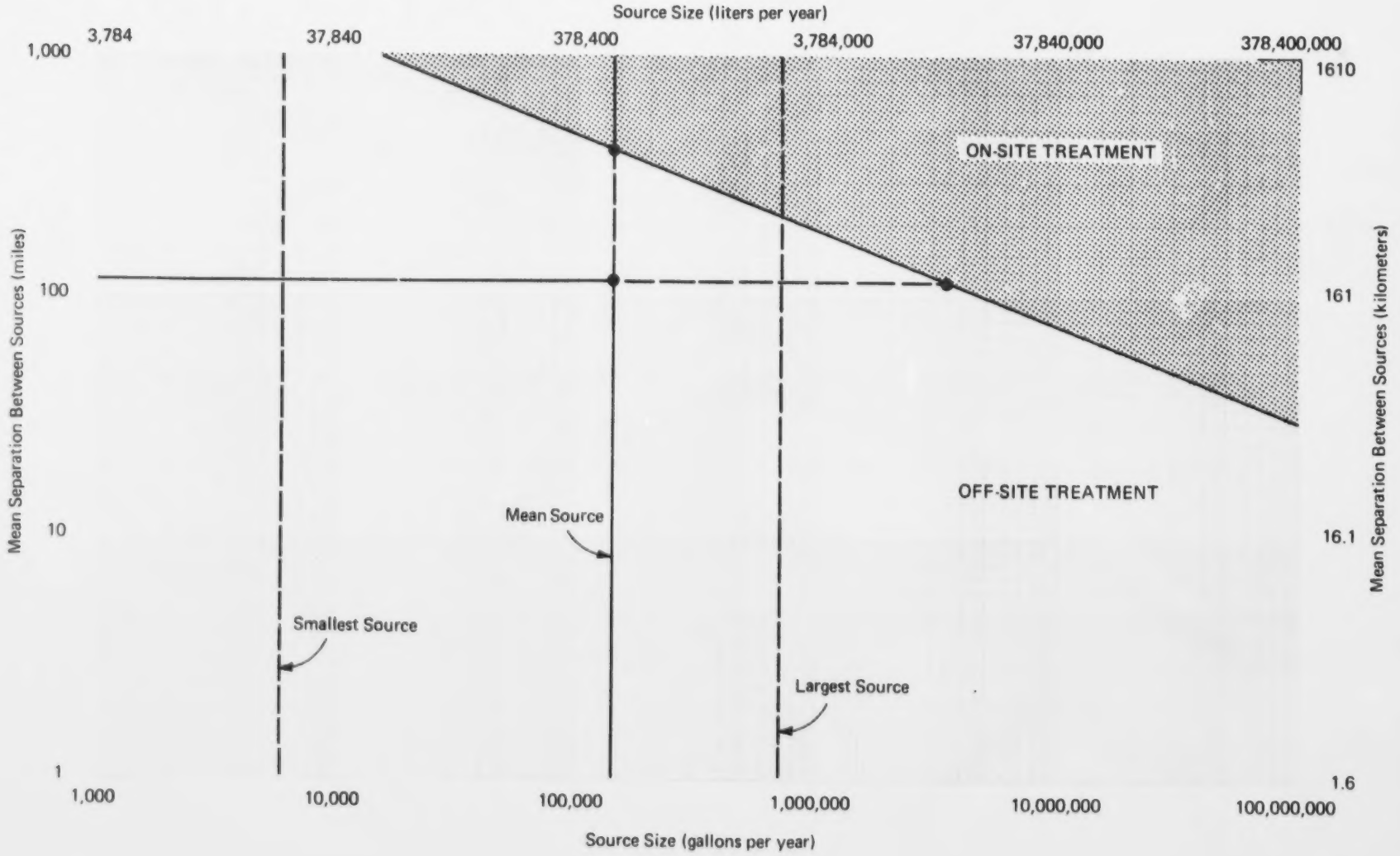

FIGURE 3.6 CONCENTRATED CYANIDES

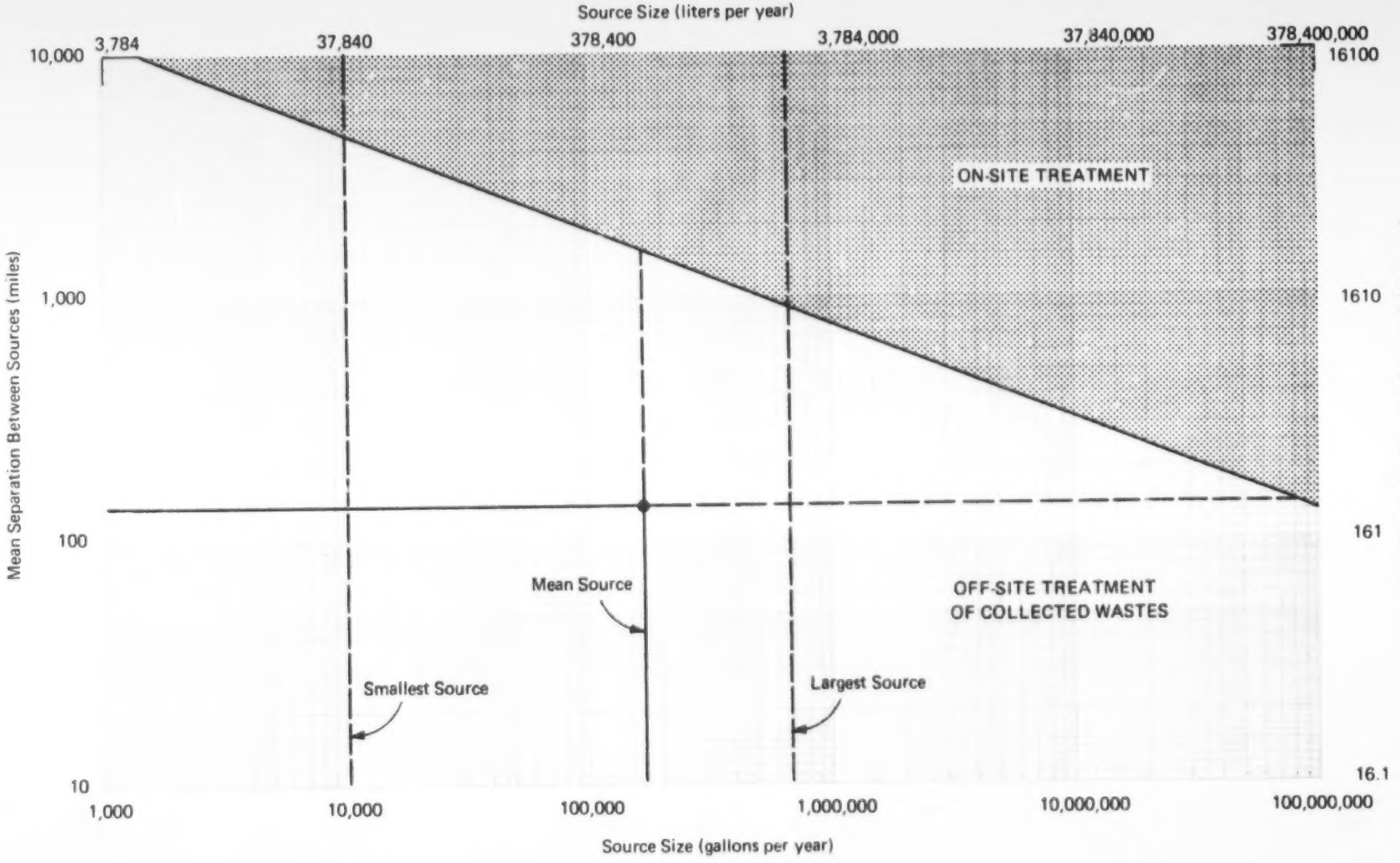

FIGURE 3.7 LIQUID CHLORINATED HYDROCARBONS

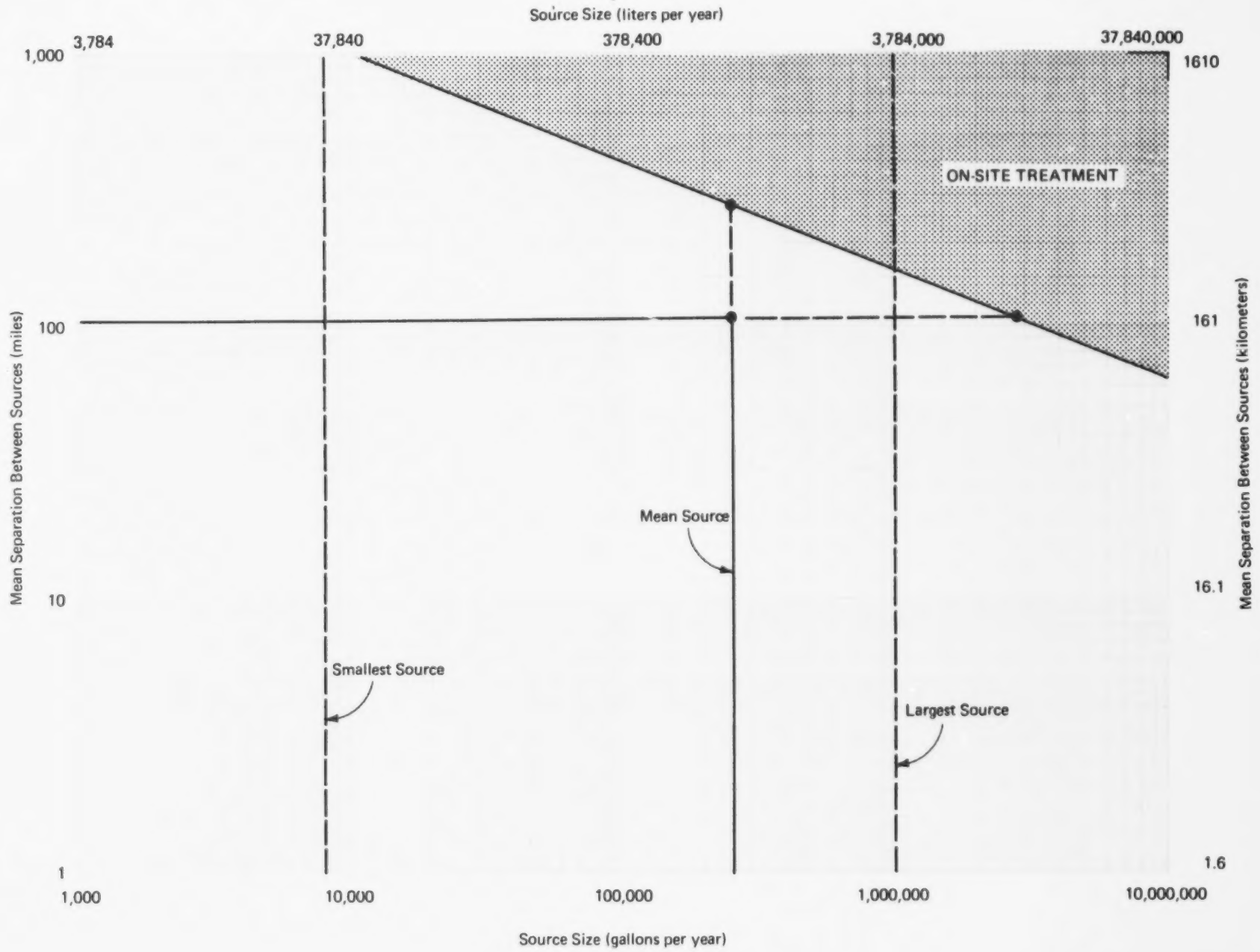

FIGURE 3.8 DILUTE CYANIDES

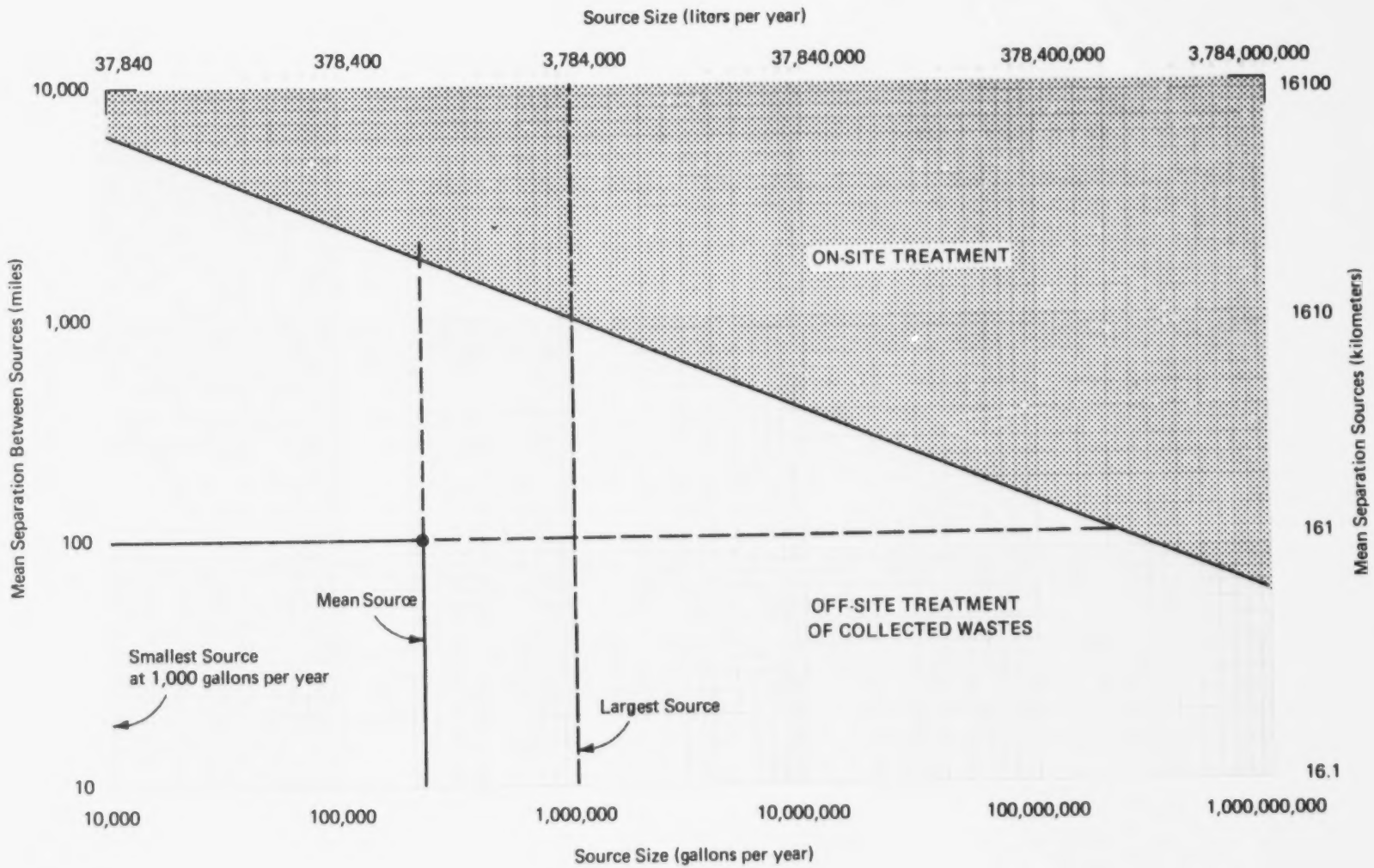

FIGURE 3.9 CHLORINATED HYDROCARBON AND HEAVY METAL SLURRIES

On the decision map for dilute heavy metals with organic contamination, Figure 3.4, two waste groups are considered. The bulk of the sample consists of wastes from the metal finishing industry and is shown in the usual manner. In addition, we identified two tanneries in another geographical area. The waste volumes from these tanneries are one to two orders of magnitude larger than the largest from the metal finishing industry and are shown separately. For the plating wastes, off-site treatment is preferable. For the tanneries, on-site treatment is preferred if the tanneries are more than 10 to 20 miles (16 to 32 kilometers) apart.

The decision map results are summarized in Table 3.5, along with information which provides a basis for evaluating the results. In all cases, except Category 3, off-site processing is recommended based on the properties of the sample mean.

Would all sources, even the largest ones, actually make use of an off-site facility if it were available? We cannot answer that question definitively, since the answer depends on the location of the large source relative to the off-site facility. However, the numbers listed in column (4) of Table 3.5 give some hint. This column shows the ratio of the source size at which on-site processing becomes feasible to the size of the largest source in the sample. The larger this ratio, the more likely that the large sources would find off-site processing attractive.

In Categories 3 and 4a, these ratios are less than one and large waste sources within these categories might well choose to process on-site. It is important to recognize that, even if this occurs, off-site facilities are still required for the smaller sources. This conclusion can be visualized on the decision map. Exclusion of large sources from the sample reduces the mean size significantly. This forces the sample point to the left on the map and more deeply into the OFF-SITE region.

For dilute heavy metals, Category 2, the recommended strategy is on-site processing. The ratio (source size at which off-site processing becomes feasible to size of the largest source in the sample) is 0.017, and the ratio to the mean source size is 0.13. These values imply that only sources smaller than 13 percent of the mean size could afford to choose off-site treatment if they are as much as 73 miles (118 kilometers) apart (the mean source separation). There is little likelihood that an off-site facility geared strictly to the treatment of these wastes would be feasible.

Column (2) of Table 3.5 shows the source separation at which the recommended alternative changes (from off-site to on-site, or vice versa), compared to the mean source separation derived from the source sample. It is important to recognize that additional sampling for waste sources can result only in a decreased mean source separation as more sources are located. In all cases except Category 2, the mean source separation is already less than that at which the strategy changes, and the addition of sources to the sample cannot change the recommended strategy unless the additional sources also cause the mean size to increase dramatically.

TABLE 3.5

OPTIMAL PROCESSING STRATEGIES

	Recommended Alternative	Separation at Which Recommended Alternative Changes (miles)/Sample Source Separation (miles)[1]	Size at Which Recommended Alternative Changes			
			Amount (gpy)	Amount (lpy) x 10^6	As Ratio to Largest Source in Sample	As Ratio to Mean Sample Size
1. Concentrated Heavy Metals	OFF-SITE	360/81 (580/130)	16,000,000	60.5	17	490
2. Dilute Heavy Metals	ON-SITE	34/73 (55/118)	100,000	0.38	0.017	0.13
3. Dilute Heavy Metals with Organics	OFF-SITE	128/94 (206/151)	1,500,000	5.7	0.43	2.0
4. Heavy Metal Sludges Encapsulation with						
a. Asphalt	OFF-SITE	105/97 (169/156)	850,000	3.2	0.24	1.6
b. Cement	OFF-SITE	450/115 (725/185)	1,250,000	4.7	9.6	28
5. Concentrated Cyanides	OFF-SITE	420/115 (676/185)	3,800,000	14.4	5.4	27
6. Dilute Cyanides	OFF-SITE	290/108 (467/174)	2,900,000	11.0	2.9	12
7. Liquid Chlorinated Hydrocarbons	OFF-SITE	1600/140 (2576/225)	80,000,000	30.3	120	500
8. Chlorinated Hydrocarbon and Heavy Metal Slurries	OFF-SITE	1800/115 (2898/185)	220,000,000	832	220	980

1. Values in parenthesis are in kilometers

The sample separation for Category 2 is 73 miles (118 kilometers), and the recommended strategy would change from on-site to off-site if the separation were reduced, to 34 miles (55 kilometers) or less. It would take four times the number of sources in the original sample to give the required 34-mile (55 kilometer) separation.

Pretreatment of Wastes

A processing strategy applicable to a wide variety of the aqueous wastes considered under the eight categories analyzed in the preceding section is concentration of the waste by an evaporation process prior to shipment to an off-site facility. The implications of this strategy for the on-site/off-site decisions have been examined. There are two basic situtations to consider. The first is on-site processing of dilute heavy metal wastes: is concentration of the waste and shipment of the concentrate to an off-site facility less costly than on-site treatment of the dilute waste? The second is the other waste categories in which off-site treatment is advocated. Can savings be made by concentration prior to shipment? The situations require separate consideration.

The cost of treating a dilute heavy metal waste on-site is simply the processing cost. Concentration of the waste and shipment to an off-site facility incurs three major cost elements: concentration, transportation, and off-site processing. Using a standard base capacity of 10,000 gpd (37,840 lpd), the total cost of on-site treatment of dilute heavy metals via precipitation and burial was estimated to be 1.1 to 1.2¢/gallon (0.38¢/l). At the same capacity, the evaporation cost was estimated to be $31.50 per thousand gallons ($8.30/1000 liters) evaporated. The evaporation cost alone, not including the transportation and off-site processing cost accrued under the preconcentration strategy, is higher than the on-site processing cost. Therefore, on-site treatment based on precipitation is preferable to preconcentration and shipment.

In the second situation, where the waste would be shipped off-site even without preconcentration, the question is somewhat more complex. The decision to preconcentrate is an individual one which can be made at each waste source without influencing the same decision at another source. However, all of the waste material winds up at the off-site facility whether or not the waste is pretreated. Preconcentration reduces the individual's transportation costs and also the off-site processing cost, since for the same amount of waste chemical, a concentrated waste is less expensive to process than a dilute one. The question is, under what conditions do these savings override the cost of preconcentration?

Figure 3.10 illustrates the situation. Total disposal cost (processing plus transportation) is plotted against distance from the source to the off-site processing facility for three alternative strategies:

(a) Shipment of dilute waste for processing off-site (Line A). This strategy has the lowest processing cost (intercept at zero distance) and the largest rate of increase of cost with distance. (A large volume of waste is shipped.)

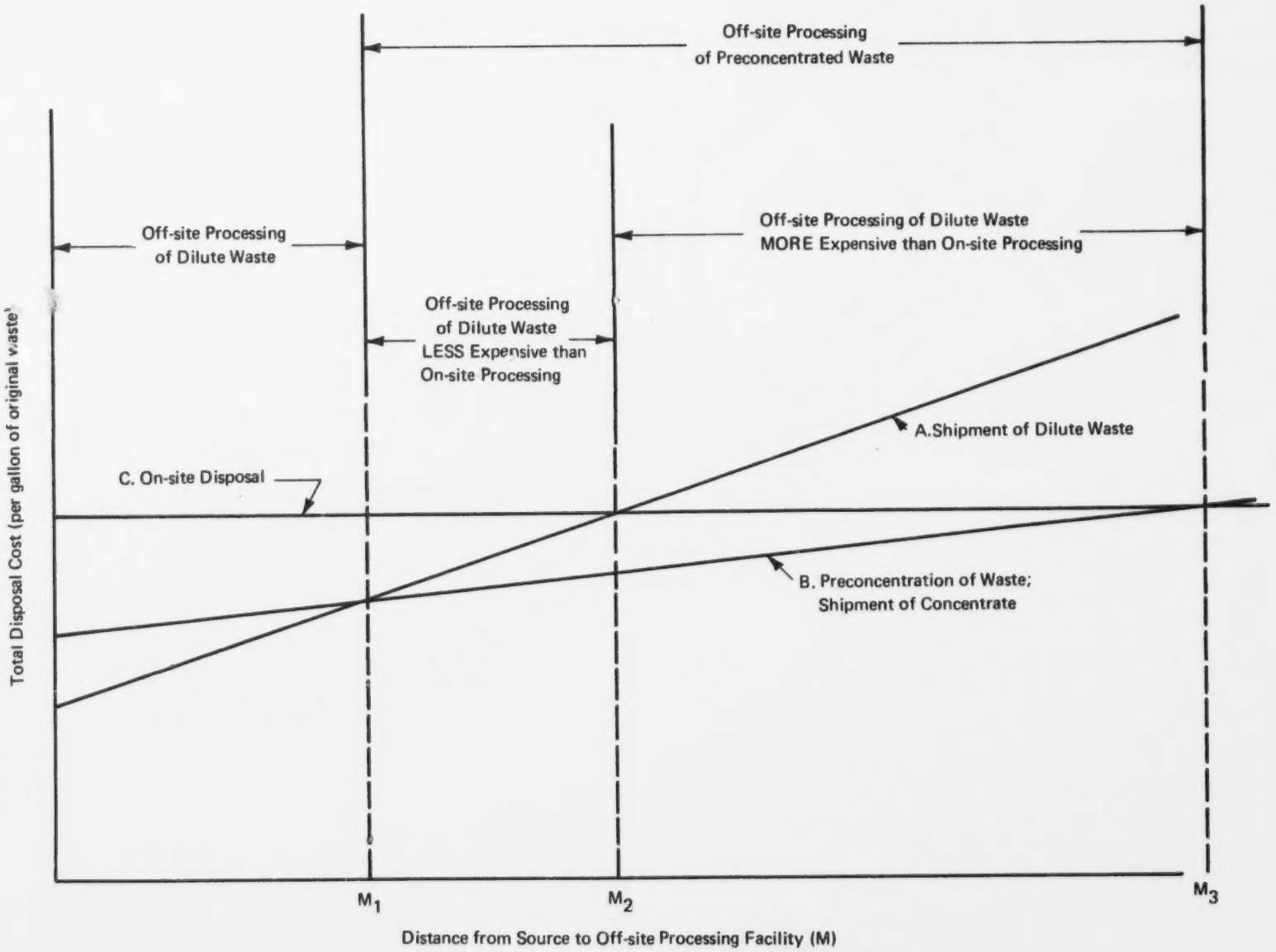

FIGURE 3.10 EFFECT OF DISTANCE TO OFF-SITE PROCESSING FACILITY ON DISPOSAL COST

(b) Preconcentration of the dilute waste on-site and shipment of the concentrate for off-site processing (Line B). Preconcentration raises the processing cost above that of (a), but reduces transportation costs per mile shipped.

(c) On-site disposal of the dilute waste (Line C). This strategy has the highest processing cost, but no transportation cost.

The intersection of these lines with each other defines the optimal processing strategy as a function of distance from source to off-site processing facility.

Figure 3.10 shows that:

1. For M less than M_1, shipment of dilute wastes for off-site processing is least expensive.

2. For M larger than M_1 and less than M_3, on-site preconcentration and off-site processing of the concentrate is preferable.

3. For M larger than M_3, on-site processing is least expensive.

Our previous analysis of on-site versus off-site alternatives considered the trade-offs between Line A, shipment of dilute wastes, and Line C, on-site disposal.

The decision maps shown earlier are based on the breakeven distance between these alternatives (M_2 on Figure 3.10). Consideration of the evaporation alternative modifies the results in two ways:

1. The cost can be reduced by preconcentration of the waste when the distance from source to processing facility lies between M_1 and M_2.

2. The distance which the waste can be economically shipped for processing increases from M_2 to M_3, although the magnitude of the cost difference between on-site processing is not large in this distance range.

The values of M_1 and M_3 are difficult to compute for general classes of wastes. They depend strongly on the degree of preconcentration carried out on-site. This in turn is limited by the composition of the individual waste, which determines how far preconcentration can be carried without severe technical difficulties arising. Difficulties to be expected in preconcentration include decomposition of chemicals in the waste with off-gassing or precipitation, and scaling or corrosion of concentration equipment.

Estimates were made of the values of M_1 for dilute heavy metal solutions and dilute cyanides. The breakeven distance, M_1, is given by:

$$M_1 = \left[\frac{1}{1-\alpha}\right] \left[\frac{c_{pp}}{c_{TW}}\right] - \left[\frac{\Delta c_p}{c_{TW}}\right]$$

where:

α is the ratio of final to initial volume in the preconcentration process.

c_{pp} is the unit cost of concentrating the dilute waste on-site.

Δc_p is the unit cost, per gallon of dilute waste, of treating dilute waste minus the the unit cost, again per gallon of dilute waste, of treating the concentrated waste.

c_{TW} is the transportation cost per gallon-mile.

If the actual distance to the off-site facility is larger than M_1, preconcentration is economic.

To illustrate the situation, the values of M_1 for several examples were computed. Using the processing costs discussed in Chapter 2 and the equations given above, it was found that values of M_1 for dilute heavy metals with organics range from about 80 miles (129 kilometers) for the largest sources found in the field survey to about 120 miles (193 kilometers) at the mean size source. For dilute cyanide solutions, comparable values of M_1 are 50 miles (80 kilometers) and 300 miles (483 kilometers).

The conclusion is that large sources relatively far (50-80 miles) (80-129 kilometers) from the off-site facility might find it economical to preconcentrate their wastes prior to shipment. Small sources would find preconcentration economical only if they were located several hundred miles from the off-site facility. (Specific distances are dependent on the nature of the waste and thus the treatment required.)

Another way to view the selected process for dilute metals (precipitation and burial) is that the precipitation step is actually preconcentration. However, for each gallon of waste the cost of sludge disposal is less than one percent of the costs for precipitation; therefore, the latter in reality is the effective processing cost. Thus, the decision map for dilute heavy metals, is also a decision map for a preconcentration step based on precipitation.

Configuration of Regional Processors

The decision map analysis also provides some insight into the optimal configuration of regional processors for those wastes best treated off-site. While a detailed analysis of this configuration is beyond the scope of this work, this report includes the preliminary result of an analysis to illustrate the power of the model.

The decision map for concentrated heavy metals is shown in Figure 3.2. The region denoted OFF-SITE PROCESSING includes varying degrees of collection; for example, one processing facility might best serve only a few sources, while under other conditions it might best serve a hundred sources dispersed over a wide area. In general, the farther into the OFF-SITE PROCESSING region one moves from the line separating the two regions, the greater the degree of collection called for.

This dependence can be shown by drawing contours of constant area served by each processing site in the OFF-SITE PROCESSING region of the map. The location of the point representing mean source size and separation relative to these contours shows the optimal configuration for a regional processor treating these wastes. For example, Figure 3.11 shows that the optimal processor configuration for serving the sample of concentrated heavy metal sources uncovered in our field work is one processing site for each 70,000 square miles (181,300 square kilometers).

This quantification of regional processor configuration is preliminary, and more detailed analysis is required for actual design of a network of processing facilities. Two important factors should be mentioned:

(1) A complete survey of sources within an area is required for network design. Adding to the sources in our sample decreases the mean separation between sources, and, as the contours show, reduces the size of the area best served by a single processing facility. The mean source separation is universally proportional to the square root of the number of sources, so doubling the number of sources in an area reduces the separation by a factor of 1.4 and therefore reduces the optimal area served by each processing facility by about the same factor.

(2) When large geographic areas are inventoried, variations in source density (mean source separation) within that area should be considered.

Table 3.6 summarizes the result of the preliminary analysis of regional processor configuration for the eight waste categories considered. The area served by each processor is listed as "maximum" since more detailed analyses would probably reduce the area for reasons described in (1) above. The corresponding separation between processing facilities is also shown.

The results vary significantly by waste category, but in each case the separation between processing facilities is more than 100 miles (161 kilometers).

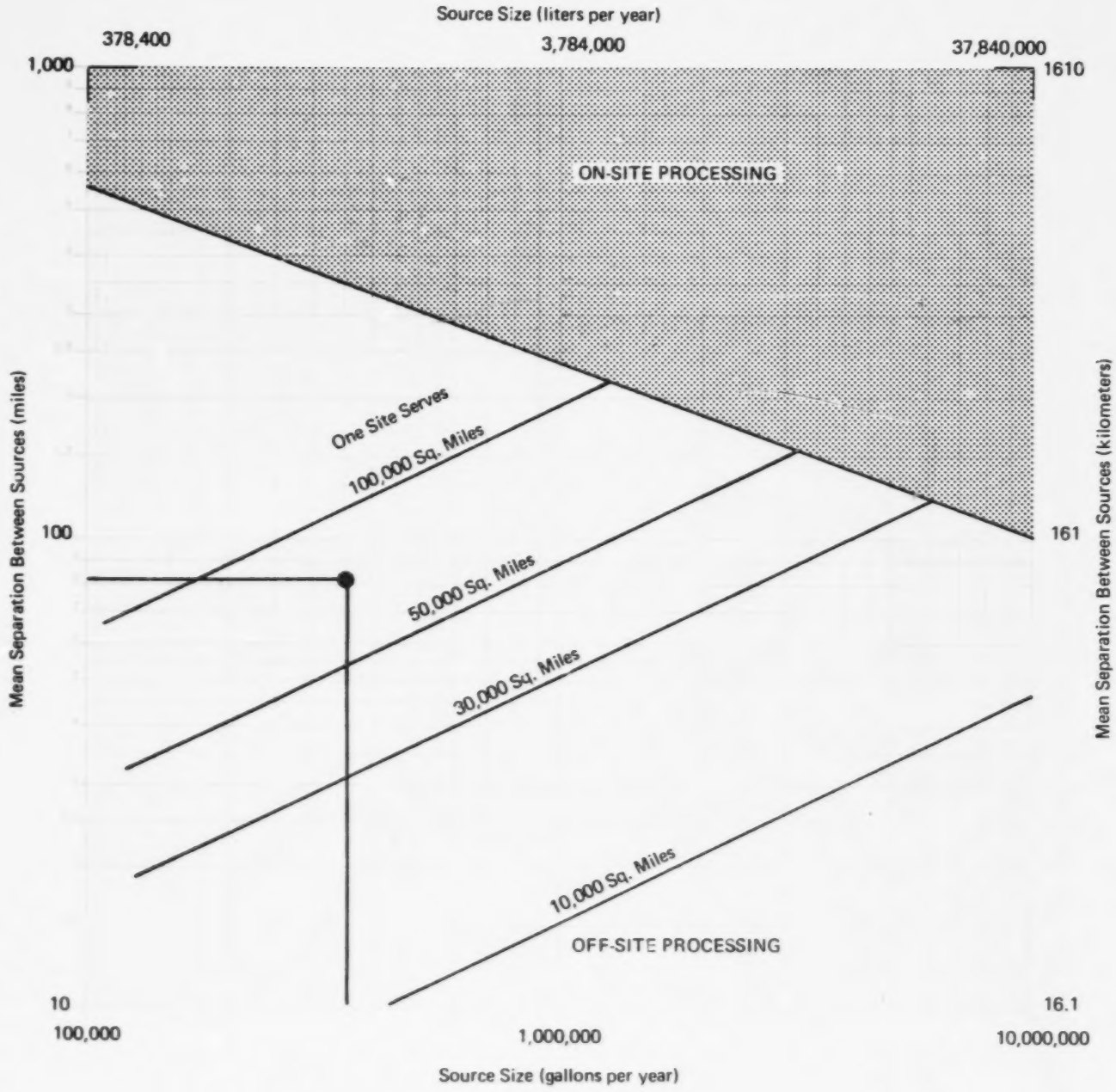

FIGURE 3.11 REGIONAL PROCESSOR CONFIGURATION – CONCENTRATED HEAVY METALS

TABLE 3.6

REGIONAL PROCESSOR

CONFIGURATION

(Preliminary)

Waste Category	Approximate Maximum Area Served One Processing Facility (sq. miles)	Approximate Maximum Area Served One Processing Facility (sq. kilometers)	Spacing Between Processing Facilities (miles) (miles)	Spacing Between Processing Facilities (miles) (kilometers)
1. Concentrated Heavy Metals	70,000	181,300	260	419
2. Dilute Heavy Metals	ON-SITE	ON-SITE	–	–
3. Dilute Heavy Metals with Organics	20,000	51,800	140	225
4. Heavy Metal Sludges, When Encapsulated in				
a. Asphalt	20,000	51,800	140	225
b. Concrete	100,000	259,000	320	515
5. Concentrated Cyanides	100,000	259,000	320	515
6. Dilute Cyanides	50,000	129,500	220	354
7. Liquid Chlorinated Hydrocarbons	500,000	1,295,000	710	1,143
8. Chlorinated Hydrocarbon and Heavy Metal Slurries	500,000	1,295,000	710	1,143

LEGAL AND INSTITUTIONAL FACTORS

Introduction

The purpose of this phase of the program was to determine whether existing statutes and regulations hinder the handling, treatment, and disposal of hazardous wastes and, from that basis of understanding, to identify what legal powers, if any, need to be enacted in order to ensure proper processing. This section first surveys and evaluates the framework of existing Federal laws which would influence the alternative strategies, and then surveys pollution control measures by various states; next it discusses questions of legal liability relating to injury or damage resulting from handling and disposal of hazardous wastes; finally, it outlines the major legislative needs for creating an effective hazardous waste management system.

The conclusion, in brief, is that present Federal and state laws do not hinder the proper handling of wastes; but with the exception of radioactive wastes regulated by the Atomic Energy Act, neither do they encourage or require proper treatment and disposal. Legislation is therefore needed to confer the authority to regulate waste treatment, to structure the Federal-state partnership in this field, to require reporting and inventory procedures, to specify standards and controls, to authorize a system of permits, and to authorize inspection of waste handling, treatment, and disposal sites.

One must keep in mind the general distinctions among: (1) statutes, (2) administrative regulations, and (3) agency practices. While most administrative regulations take on the force of law, an important distinction remains between legislatively-enacted statutes and administrative regulations. Administrative rules and regulations must fall within the bounds of a statutory standard set by the legislative body. Regulations can be changed with relative ease and speed, whereas statutes must await the more deliberate acts of legislatures. Both statutes and regulations are, of course, subject to judicial interpretation and the test of constitutionality; however, any regulation must remain not only within constitutional bounds, but also within a statutory standard, however broad. Administrative practice and behavior may have the same practical force of law for an affected party who cannot afford time and/or money to challenge it in court. In summary, describing the legal framework in hierarchical terms, the descending order of importance of the elements is: constitutional provisions, statutes, regulations, and administrative practice.

Federal Approaches to Abating Pollution

The Federal Government traditionally has left to the states the role of establishing and enforcing air and water quality standards. When it has taken action, it has done so in two ways. One has been to detect and deal with pollution after it has occurred. Although this is clearly not the most effective strategy to reduce pollution, it has attracted the broadest political support.

In general, the most effective statute has been the Refuse Act of 1899. This law has recently been applied, thanks to broad judicial interpretation, to waste discharges of many kinds. Its strength lies in three areas:

(1) It authorizes immediate court action, instead of allowing the long delays characteristic of procedures under later Acts;

(2) Violators can be convicted even if pollution complies with water quality standards; and

(3) Applications for discharge permits have to include data on composition and volume of wastes.

The alternative method, to regulate polluting substances before they enter the environment, has not been pursued vigorously until recently. Although the Federal Water Pollution Control Act (FWPCA) of 1965 stated a policy of preventing water pollution, its enforcement powers applied only after pollution occurred; it relied on the states to set water quality standards, but allowed the Federal Government to step in and set standards if a state failed to do so.

Congress improved Federal strategy considerably with the landmark Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500; 33 U.S.C. 1251-1376). This amended, reorganized, and expanded FWPCA attempts to close many of the loopholes in the existing statute as well as tighten Federal controls. Its important aspects regarding hazardous wastes include:

- extending pollution control, liability and enforcement provisions to hazardous substances as well as oil;
- extending Federal control to all U.S. waters;
- setting up a permit system to replace the Refuse Act of 1899 with strong regulation of industrial waste; and
- creating effluent limitations backed by strong standard-setting and enforcement provisions.

Similarly, the proposed "Toxic Substances Control Act" would regulate substances before allowing them to be marketed. This legislation was submitted by the President in 1972 and passed by the Senate, but died upon expiration of the 92nd Congress; it was reintroduced after the 93rd Congress convened in 1973.

Several existing statutes confer powers to act before pollution occurs, for example, the Clean Air Act (auto emissions regulations and testing), National Environmental Policy Act (requiring an impact statement before beginning a project), Federal Insecticide, Fungicide, Rodenticide Act (requiring registration and labeling before use), Food, Drug, and Cosmetic Act (registration and labeling before use), Hazardous Substances Act (requiring labeling), and Atomic Energy Act (total control of radioactive substances). The enforcement powers of most of these acts, with the notable exception of the Atomic Energy Act, are weak or non-existent. Nevertheless, they do show Congress's concern for threats to the environment and the general health. Another statute which proclaims an overall policy and authorizes financial aid but confers no enforcement powers is the Solid Waste Disposal Act.

Federal authority is stronger in the field of transportation. Acts regulating carriage of explosives and hazardous substances such as flammable liquids reflect both accidents and public apprehensiveness about catastrophes on land, for example, from explosions of trains carrying munitions or poison gas, and on water, for example, from oil spills. The Department of Transportation administers five laws, for instance, the Hazardous Cargo Act, that require proper packaging, labeling, reporting, and handling.

These laws and resulting regulations have provided models for similar requirements by a number of states seeking to cope with at least the dramatic incidents which can occur with hazardous substances. They reflect the psychological observation, reported in the discussion of risks, that public consternation, and political support for regulatory action by government, is aroused less easily by a series of minor accidents than by a major disaster. A court test might lead to a ruling of Federal preemption in this field of law where both Federal and state governments have interests.

These laws provide both a legal framework and a data base of administrative experience in one important aspect of the handling of hazardous wastes. They both hinder unregulated transportation of hazardous wastes in interstate commerce and facilitate orderly transportation by providing uniform national controls.

Turning to the less-than-dramatic aspects of handling hazardous wastes, several problems seem important. Some are common to intergovernmental relations in many fields. The major one, of course, is whether Federal or state governments are more capable of ensuring proper handling or, if neither is clearly best, what system of sharing responsibilities will achieve the desired results. At one extreme is the radioactive substance model, in which Federal Government, through the Atomic Energy Commission, exercises total control and enjoys strong enforcement powers. At the other is the traditional model by which questions of health and environmental quality were, before the 1960s, left largely to the states, which

in turn often delegated them to local governments. But administrative necessity tends to render these extreme models more theoretical than real: even the Atomic Energy Commission, although it retains authority to set standards and monitor performance, delegates operating responsibility to those states which qualify and desire it.

Some problems relate specifically to the technical characteristics of hazardous wastes. Which of the several tools of control are most effective for dealing with them? The Federal Insecticide, Fungicide and Rodenticide Act, the Hazardous Substances Act, and the Food, Drug, and Cosmetic Act use labels to warn consumers of the dangerous nature of what they are buying and using; but this warning protects neither the user from himself nor innocent companions such as children. The issuing of permits, as in the Refuse Act, places the burden of decision on the issuer and the holder of the permit rather than on downstream users of water. Where in the "life cycle" of an individual waste, given its chemical characteristics, can it be controlled most effectively? It may be impossible to prescribe a general rule other than to control the substance, especially if it is a mixture of several chemical pollutants, before it does any harm.

In the past, environmental protection efforts have been focused, for good reasons, on only one medium at a time. But now, because of the variety of substances that may be considered hazardous wastes, all three media – water, air, and soil – must be protected. In addition, the existence of hazardous wastes in all media must be inventoried: even though the amounts in each medium may not be damaging when evaluated separately, their cumulative and total effect may well be dangerous. What is the best standard or measure for each substance, in each medium? The Clean Air Act provides that each substance be assigned its individual standard within overall ambient air quality standards. Because of the complexity of substances, this may be the best way, even if unwieldy, for other media.

Of the three media, standards and control methods for air are already being vigorously developed under the Clean Air Act, and the water quality control will be substantially upgraded by the FWPCA Amendment of 1972. But land, the ultimate sink for many polluting wastes, including those discharged initially into air and water, remains unprotected by comprehensive Federal or state laws. The next legislative frontier is to create authority to regulate the use of land as the ultimate disposal medium for hazardous wastes.

Overview of State Pollution Control Measures

The Federal Government has traditionally relied upon the states to control air and water pollution. In recent years, however, Congress has specifically directed the states to establish air and water quality standards. Currently, all states have basic air and water pollution control legislation; they have also developed or are in the process of developing program strategies and plans.

While the specific provisions vary greatly from state to state, their laws have several elements in common. Several states have specifically granted to individual citizens the right to initiate lawsuits for the protection of the environment. Delaware, Maine and Vermont

have developed statewide land-use controls, reflecting a definite trend of increased regulation over use and development of land.

State laws and regulations may be classified broadly into a few categories. Water quality laws have the longest history. Air quality laws, of recent origin, generally parallel water laws in strategy. Solid wastes have received attention most recently from states, although municipal governments have traditionally exercised jurisdiction over dumps and sewers.

Water effluent standards, as required by the Federal Water Pollution Control Act, have been promulgated by all states. Federal approval by the EPA has been granted for all but a few states. States have approached the control of water pollution in various ways. One common technique is to establish a permit system: 46 states, Pennsylvania and New Jersey among them, have wastewater discharge regulations which require registration and the issuance of a permit. Maryland has established a state-wide, state-level sanitary district empowered to take over waste treatment functions which have been traditionally handled by municipalities. Thirty-two states now provide tax incentives to private industry to construct waste treatment facilities. The FWPCA Amendments of 1972, enacted over President Nixon's veto in the closing days of the 92nd Congress, accelerates the drive to improve water quality.

States have often lacked adequate powers to manage proper disposal of solid wastes. Their traditional authority, based on general health and/or nuisance laws, controlled the dumping of refuse on public and private property. But recent recognition of the magnitude of the problem has made planning more acceptable. Many states have, with Federal financial assistance, conducted statewide studies to develop recommendations for solid waste management. Maryland, New Hampshire, and Pennsylvania have enacted legislation requiring local governmental units to prepare comprehensive management plans. New York has carried out a state-financed sewerage study covering the entire state on a region or county basis.

Concerning hazardous substances, almost all states have some regulations. Often, as in Texas and California, they are modelled on provisions in the Code of Federal Regulations and focus on the transportation of hazardous substances. In New Jersey and Pennsylvania, large industrial states which have experienced dramatic spills and accidents, regulations emphasize control of industrial wastes. California passed in 1972 a strong bill specifically controlling hazardous wastes; the new law confers regulatory powers on the California Department of Public Health, requires a listing of wastes, provides for supervision of their handling and disposal, and provides civil enforcement procedures.

California's Water Quality Council adopted July 6, 1972, regulations to implement the "State Policy for Water Quality Control." The Council strongly states (1) that treatment of hazardous substances is part of efficient wastewater management, and (2) that treatment must provide sufficient removal of hazardous substances to guard against adverse effects on the water for beneficial and community use.

New York's legislature recently passed a comprehensive act dealing with all aspects of handling and management of "substances hazardous to the environment."

Some states have recently passed constitutional amendments establishing an "environmental bill or rights," or comprehensive policy statements. These states have thus established broad legal authority for dealing with all aspects of pollution, and the threat of pollution, in any medium of the environment.

An important administrative trend is to reorganize those departments or agencies which have had jurisdiction over pieces of the environment into "superagencies." These seek to exercise comprehensive control over many aspects of pollution. Thirteen states already have working environmental departments; two, New Jersey and Pennsylvania, are discussed in Appendix E. There seem to be several reasons for these consolidations:

- to create a strong regulatory agency which is visible and accountable, both to other government agencies and to the general public;
- to coordinate programs of previously separate, and sometimes competing, agencies;
- to improve both the efficiency and professional standards of environmental programs;
- to parallel consolidation of Federal agencies.

Despite these encouraging signs of progress, however, state governments still face basic and persistent problems. A familiar one is severe shortages of appropriations to implement environmental protection laws. The states generally still rank far behind the Federal Government in matters of technical and administrative manpower, often because of unattractive pay scales. Officials are too often reluctant or unable to impose regulation on politically-powerful polluters and land developers.

Legal Liability Issues

The major issues are two:

- To what extent have statutory developments altered common law principles relating to liability for abnormally dangerous activities?
- Is the law in this area principally Federal, state or municipal?

Two areas of the law apply to disposal of hazardous wastes: torts and criminal law. The only distinctions to be made for this purpose between tort liability and criminal liability relate to the generality of interests affected and the remedies afforded by the law.

The issue of tort liability is resolved in a civil action brought by a private plantiff representing his personal interest, whereas criminal liability is determined in an action brought by a public official representing broad societal interests. The remedy in a tort action is money damages that compensate actual harm done or an injunction to stop the activity, while criminal liability results in a fine and/or imprisonment, often regardless of whether any harm was done.

While there are some common-law crimes, the dumping of hazardous wastes is not one of them. In the absence of statute, such dumping would not constitute a crime. This is true whether the question is dumping per se or any harm that may result to property or person as a consequence of such dumping.

A tort action could be brought by a private party basing the case on a number of different common-law theories, or by a government agency pursuant to statutory authority where such authority exists. A variety of Federal statutes, such as the Rivers and Harbors Act of 1899, empower Federal officials to bring criminal actions against polluters. However, it is probably fair to say that the basic law relating to collection and disposal activities, as opposed to violations by industrial firms, is primarily a matter of state and local jurisdiction. As a general rule the supervision of the removal and disposal of all types of refuse and waste is an affirmative duty that is imposed and delegated by the state upon municipalities pursuant to state statute. Primarily for reasons of governmental economy, local governments have usually limited their collection and disposal activities to non-industrial wastes. However, basic jurisdiction over all waste collection and disposal usually remains at the local level. There are likely to be a variety of state and local statutes assessing fines for dumping violations; however, private harm is compensated through the particular jurisdiction's law of torts.

When an industrial firm hires contractors to dispose of its waste, as is usually the situation, the firm still must comply with local codes and regulations. In addition, some states, such as New Jersey, regulate collection and disposal activities at the state level through public utility commissions. There may be specific statutes setting standards for the disposal of hazardous materials in some states, but that is probably not the rule. Where such statute or local code has been violated during the collection and disposal process and damage to life or property results, not only may fines be imposed but suit may be brought by injured plaintiffs on a variety of tort theories. The suit may be based on a theory of absolute liability, or negligence, or even nuisance. Most states would adhere to the rule of law that one who by statute or by administrative regulation is under a duty to provide specified safeguards or precautions for the safety of others is subject to liability to the others for whose protection the duty is imposed for harm caused by the failure of a contractor employed by him to provide such safeguards or precautions. Thus, an industrial firm would be liable for harm done by his collector and disposer of hazardous wastes in the event the contractor violates some statute or code during his operations. Where code violation is involved, tort liability of the industrial firm is absolute.

Even when no statute exists or has been violated, tort liability may be imposed on the industrial firm in the event that his contractor has been negligent or creates a nuisance in the process of collecting and disposing of the firm's refuse. This liability for the industrial firm is present even when the industrial firm has specifically instructed the contractor to take the necessary precautions.

If the collecting and disposing organization is a governmental organization, an added complication is present. Under the common law doctrine of sovereign immunity, governments are exempt from suits except where they specifically waive such exemptions. At the Federal level, the Federal Tort Claims Act would provide a mechanism for injured parties to sue a Federal instrumentality that caused damage in the course of its disposal activities. Similarly, a specific statute could provide such a right of action.

Statutes similar to the Federal Tort Claims Act have been enacted in certain states, but courts must still often be creative in finding a theory which will allow private suits. The theory often used is that a governmental agency which is engaged in an essentially business activity, such as waste collection and disposal, has waived its immunity.

Perhaps the most pressing concern in the area of hazardous waste disposal liability relates to insurance. Presumably, certain ultra-hazardous wastes could cause such extensive damage that a private concern would be unable to compensate the victims. Some form of pooled risk coverage or Federally underwritten coverage similar to flood and riot insurance seems desirable.

Legislative Needs

The foregoing discussions of Federal laws, state laws, and liability issues lead to the conclusion that no major statutory obstacles would hinder development of a hazardous waste management system which includes central processing facilities. Some adjustments would be required, of course, for example, in present laws regulating transportation of hazardous substances; but these would not present insurmountable problems.

The need, instead, is to legislate the authority for creating, administering and enforcing a waste management system. Whether the system consists of on-site treatment and disposal by waste generators or shipment to off-site central processing facilities, the legal and administrative needs are the same: Federal and state agencies must be authorized to regulate hazardous wastes; they must develop and maintain lists to identify and classify wastes; they must specify standards for controlling effluents if not the waste-generating processes themselves; they must be able to require adequate record-keeping by waste generators and to inspect treatment and disposal sites to ensure proper observance of standards; and adequate judicial powers must exist to back the efforts of these agencies. States can and should follow the example of California in enacting their own laws to address the hazardous waste problem. But a Federal role is also required. The immediate need, therefore, is Congressional action to demonstrate the Federal interest, especially in land disposal, to establish the basic Federal approach, and to structure the Federal-state cooperative relationship.

RISK CONSIDERATIONS

Introduction

It is important to reiterate at the outset that in analyzing risks to society in the manner described in Part 2 new ground is being broken. Thus, even though this work represents only a preliminary study of the problem, the conclusions are useful in setting some estimates on the magnitude of the problem. However it is recognized that such an approach for quantifying risks could be improved upon, and could possibly become a powerful tool for determining the acceptability of all types of risks that technology presents to society.

Part 2 and Appendix D treat the general methodology for arriving at the risks to which society may be exposed during the transportation of hazardous chemical wastes and the levels that appear to be acceptable for those risks that can result in human fatality. Within the time limitations of this work, an acceptable level of water pollution was not derived, although one approach that appears promising is suggested.

This section discusses the results and conclusions reached in assessing the risks of transporting the various categories of wastes.

Risk from Fire

To evaluate the magnitude of the risk from fire to individuals along the route of travel, the waste identified in Appendix B, Table B.2.H as H-11 which is essentially gasoline, was used as an example. One million gallons are produced every year and trucked in 5000-gallon (18,920-liter) trucks to a disposal site. This example was chosen because it provides the worst condition.

Inspection of the risk equation shows that the length of the trip is immaterial. The risk depends only on the probability of a spill for this mode of transportation, the probability of a fire for a given spill, the number of trips per year, and the kill radius.

For this example:

P(a) = 36×10^{-8} accident/vehicle mile
(22×10^{-8} accident/vehicle kilometer)

P(f/a) = 1 fire/accident (conservatively assuming that every accident results in a fire)

R = 185 feet (56 meters)

n = 200 trips/year
(1,000,000 gallons per year/5,000 gallons per trip*)

The calculated risk of transportation for this example is 4.5×10^{-11} fatality/person-hour exposure. This is lower by two orders of magnitude than Starr's suggested acceptable level of 10^{-9} fatality/person-hour exposure and lower than the risk of dying in a flood (see Table D.1 in Appendix D).

Risk from Explosives

As indicated in Part 2, "off-spec" explosives are generally shipped in small quantities. Although no explosive wastes were identified in the geographic region of concern, the risk for an explosive shipment by truck was calculated. A kill radius of 500 feet (152.4 meters) was used and this led to a calculated risk of about 10^{-12} n fatality/person-hour exposure, where n is the number of trips per year along a certain route. Even if the explosions occur 100 times more frequently than accidents, this risk level is lower than the acceptable risk of 10^{-9} as long as the number of trips, n, is less than 1000 per year.

Risk from Toxic Gases

The risk of shipping CW agents was shown to be 8×10^{-12} n fatality/person-hour exposure. This level would also be acceptable as long as n is less than 125 trips per year.

Risk from Polluting Wastes

The maximum volume of water that could be polluted annually from spills of typical wastes containing heavy metals, cyanides or chloro organics (e.g., DDT) has been calculated. The calculation was made using truck transportation and 5000-gallon (18,920-liter) shipments. The results are shown in Table 3.7.

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*3.9 million liters per year/18,920 liters per trip.

TABLE 3.7

MAXIMUM VOLUME OF WATER THAT MAY BE POLLUTED ANNUALLY DUE TO ACCIDENTAL SPILLS

Code	Hazardous Waste	Gallons/Year	Liter/Year ($\times 10^6$)	Liters of Water Polluted/Year
A-3	2-3% Sodium Arsenite and Arsenate, 1-2% Aniline in 10% NaCl	6,000,000	22.7	3.8×10^6
A-6	8.5% Chromic Acid 20% H_2SO_4 with traces of Iron and Lead	66,000	0.25	2.4×10^7
A-9	14% Chromic Acid in 10-30% H_2SO_4	520,000	1.9	2×10^8
B-8	5000 ppm Chromium, 1500 ppm Nickel 300 ppm Copper in 15% HCl-HF-HNO_3-H_2SO_4	3,600,000	13.6	3.5×10^6
E-1	7% Sodium Cyanide 2% Sodium Hydroxide	300,000	1.14	4×10^7
F-1	50 ppm Sodium Cyanide 1% Sodium Cyanate	120,000	0.45	1.5×10^6
F-6	7000 ppm Copper Cyanide	200,000	0.76	1.5×10^6
G-1	30% DDT	20,000	0.08	1.2×10^8

In the absence of an "acceptable" level of risk for water pollution, these numbers will have to be used to compare the relative risk between alternative sites or alternative transportation schemes. Eventually, when a more realistic acceptable level of pollution is determined a more meaningful description of an acceptable level for water pollution can be derived. It is felt that this area is worthy of further study.

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